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Delphine Vettese

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THESE

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Delphine Vettese

Le 17 décembre 2019

**Approche techno-culturelle de la fracturation des os longs chez les
Néandertaliens (Sud-Ouest de l'Europe, MIS 5-3) :
une systématisation des gestes ?**

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Montag sentait la lente fermentation des mots, leur lent frémissment. Et quand viendrait son tour, que pourrait-il dire, que pourrait-il offrir en ce jour, pour agrémenter un peu le voyage ?

Toutes choses ont leur temps. Oui. Temps d'abattre et temps de bâtir. Oui. Temps de se taire et temps de parler. Oui, tout ça. Mais quoi d'autre ?

Ray Bradbury, Fahrenheit 451

Je dédie ce travail à Angeline Baude.

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Liste des publications issues de la thèse

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*Approche techno-culturelle de la fracturation des os longs chez les Néandertaliens (Sud-Ouest de l'Europe, MIS 5-3) :
une systématisation des gestes ?*

Chapitre I.

Introduction

*Approche techno-culturelle de la fracturation des os longs chez les Néandertaliens (Sud-Ouest de l'Europe, MIS 5-3) :
une systématisation des gestes ?*

I. 1. Contexte et problématiques

Les traditions dans le monde néanderthalien et pré-néanderthalien sont généralement abordées sur la base des comportements techniques liés au matériel lithique et aux aires d'approvisionnement en matières premières. La caractérisation des pratiques et des savoir-faire paléolithiques sur la base du registre osseux est une approche encore peu développée pour aborder les pratiques socio-culturelles. Des études se sont intéressées à l'apport des stratégies cynégétiques pour apporter des informations sur l'existence de pratiques de chasse collectives et organisées (Castel et al. 2017; Daujeard et al. 2017; Gaudzinski 1995; Thun Hohenstein and Peretto 2005). Les stries de boucherie enregistrées sur le registre osseux ont aussi permis de mettre en évidence des pratiques standardisées (Moncel et al. 2012; Soulier and Costamagno 2017; Stiner et al. 2009). Ces techniques montrent une meilleure maîtrise des gestes de découpe et une dextérité accrue. Les marques laissées par la récupération de la moelle osseuse ont récemment permis de démontrer la présence de pratiques bouchères standardisées et contre intuitives. Ainsi, sur le site de Bolomor en Espagne (MIS 5, Level IV), la mise en évidence de schémas de distribution des marques de percussion a permis d'identifier pour la première fois des traditions bouchères dans un site du Paléolithique moyen (Blasco et al. 2013).

Suite à la publication de Blasco et al., 2013, nous souhaitons étendre le corpus de sites néandertalien étudiés pour discuter de la présence éventuelle de traditions bouchères. Les sites de l'Abri du Maras, de la grotte de Saint-Marcel et de Riparo Tagliente (MIS 3-4) nous ont semblé appropriés pour une telle étude car ils présentent les caractéristiques suivantes:

- accumulations quasi-exclusivement anthropiques avec une quantité faible de marques des carnivores sur les os ;
- des surfaces osseuses relativement bien conservées
- des traces témoignant que toutes les étapes de la chaîne opératoire bouchères avaient été réalisées *in situ* ;
- tous datés de la phase récente du Paléolithique moyen

Nous avons choisi deux niveaux de chaque site afin de comparer les pratiques à la fois entre des sites sub-contemporains mais aussi au sein de chaque site pour observer de possible changements au cours du temps. Presque tous les assemblages fauniques des niveaux choisis présentent un spectre faunique quasi monospécifique avec une chasse préférentielle de cervidés (cerfs, rennes ou chevreuils). Par conséquent, les stratégies cynégétiques sont relativement

proches et peuvent permettre une mise en perspective des traditions bouchères avec des pratiques de chasses spécifiques.

Dans ce cadre, notre recherche s'est inscrite dans la continuité de ces travaux basés sur les marques de percussion dues à l'extraction de la moelle. A la fois, à l'échelle régionale mais aussi à l'échelle d'un site, nous avons tenté de mettre en évidence des traditions bouchères en contexte néandertalien. L'identification de ces traditions implique la transmission de savoir-faire spécifiques, de pratiques qui perdurent dans le temps et qui pourraient être typiques d'une région.

Dans ce contexte, nous définissons traditions bouchères comme des pratiques de traitement des carcasses, en particulier ici des os longs, à la fois, standardisées et contre-intuitives qui sont transmises d'une génération à l'autre dans un groupe humain, ici des Néandertaliens.

La notion de tradition est opposée à celle d'intuitivité car l'intuitivité est l'appréhension immédiate qu'un individu sans aucune expérience a lorsqu'il casse des os pour la ou les premières fois. Cette appréhension peut être influencée par des contraintes anatomiques, morphologiques ou des caractéristiques propres à l'os ou propres à l'individu.

Ce projet s'est attaché principalement à déceler la présence de traditions bouchères dans de nouveaux sites néandertaliens du Sud-Ouest de l'Europe, à partir de l'étude des marques de percussion sur les os longs.

Avant de tester la distribution des marques de percussion sur les os longs, et de pouvoir identifier des gestes standardisés et par là même mettre en évidence des traditions bouchères, nous nous sommes interrogées pour savoir quelles sont les marques de percussion que nous devrions prendre en compte dans cette étude ? Il nous est en effet apparu primordial de distinguer les marques résultant directement de l'action de percussion, de celles consécutives à la fracturation.

Comme nous l'avons vu précédemment, nous définissons les traditions bouchères par contraste avec des comportements intuitifs. Nous avons également cherché à répondre aux questionnements suivants :

- existe-t-il une ou des manières intuitives de fracturer pour récupérer la moelle des os longs d'un animal ?
- quelles pourraient-être les variables influençant cette approche intuitive ?

Pour y répondre, nous avons mis en place une vaste expérimentation.

Sur la base de l'étude des assemblages fauniques de trois sites néandertaliens (Abri du Maras, la grotte de Saint-Marcel et Riparo Tagliente), nous avons tenté de savoir :

- pouvons-nous mettre en évidence de nouvelles pratiques d'extraction de moelle standardisées et contre intuitives ?
- si c'est le cas, dans quelle mesure peut-on les différencier ?
- Sur la base de ce registre osseux archéologiques nous est-il possible de mesurer l'impact des biais taphonomiques sur l'identification et la préservation des marques de percussion ?

L'étude du matériel faunique à travers l'analyse de la distribution des marques de percussion produite lors de la fracturation permet d'émettre des hypothèses sur l'existence de gestes standardisés.

*Approche techno-culturelle de la fracturation des os longs chez les Néandertaliens (Sud-Ouest de l'Europe, MIS 5-3) :
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I. 2. Etat de l'art

I. 2. 1. Changements des pratiques

Aux alentours de 400 mille ans, parmi les groupes humains qui peuplent l'Europe et le Proche-Orient, de nouvelles stratégies de subsistance émergent. Ces stratégies concernent non seulement les techniques de chasse aux grands herbivores, avec la réalisation de véritables armes de jet (épieux en bois à Schönningen, Basse Saxe ou traces de projectile sur les os à Neumark-Nord, Thuringe, Allemagne) et l'identification de chasses collectives organisées, mais également les procédés de traitement des carcasses animales avec l'émergence des premières traditions bouchères parmi les populations néandertaliennes (e.g., Basco et al. 2013; Blasco and Fernández Peris 2012; Daujeard et al. 2017; Delagnes and Rendu 2011; Gaudzinski-Windheuser et al. 2018a,b; Gaudzinski-Windheuser and Kindler 2012; Hutson et al. 2012; Rodríguez-Hidalgo et al. 2017; Sam 2009; Turner et al. 2018). La plus grande densité humaine, la complexité des réseaux sociaux ou encore la disponibilité de nouvelles niches écologiques (steppes à mammoths favorables aux grands ongulés grégaires) ont pu être les paramètres nécessaires à la transmission culturelle à plus grande échelle (e.g., Carrión and Walker 2019; Gamble and Roebroeks 1999; Roebroeks 2001; Sykes 2012). Au sein des groupes, les analyses sur les stratégies de subsistance indiquent des pratiques nouvelles : transports des morceaux de carcasse au camp; traitements des meilleurs morceaux; connaissance des variations des structures anatomiques des proies. Ces dernières vont se généraliser et s'organiser. Ces nouvelles pratiques de subsistance sont à mettre en parallèle avec d'autres innovations majeures, comme l'usage maîtrisé du feu ou l'acquisition de nouvelles méthodes de débitage (Roebroeks and Villa, 2011a; 2011b; Stiner, Gopher and Barkai, 2011; Moncel, Moigne and Combier, 2012; Shahack-Gross et al., 2014; Shimelmitz et al., 2014; Sorensen, 2017).

Les questions liées aux relations culturelles et aux comportements standardisés comme témoin d'une transmission intergénérationnelle, d'une tradition, peuvent être approchées grâce à l'analyse des restes fauniques (Yellen 1977). L'apprentissage et la communication au sein d'un groupe à travers le temps sur un même site peut se retrouver dans des comportements standardisés. Ces nouveaux comportements sont encore largement dominés par des pratiques individuelles (e.g., Daujeard et al. 2012; Huguet-Pàmies et al. 2001; de Lumley et al. 2004; Marín et al. 2017; Moncel and Daujeard 2012; Stiner et al. 2011). Des sites tels que Qesem (Israël), Schönningen (Allemagne), Romani (Espagne), Roc-Marsal et Orgnac 3 (France) attestent du perfectionnement des techniques bouchères et d'un accès plus fréquent aux meilleurs morceaux

(e.g., Blasco et al. 2019; Daujeard et al. 2012; Hutson et al. 2012; Moigne et al. 2016; Saladié et al. 2011; Stiner et al. 2009; Voormolen 2008).

Dans ce contexte, pour le Paléolithique moyen, les hypothèses sur l'organisation sociale des groupes humains par le registre osseux fossile sont principalement basées sur les techniques de chasse. Par exemple, aux sites d'abattage en masse de grands ongulés sont associés des chasses organisées (Wallertheim, Rhénanie-Palatinat, Allemagne ; l'Abri du Maras, Ardèche ; les Pradelles, Saône-et-Loire ; Mauran, Haute-Garonne ; Tournal, Aude, France), nécessitant la présence de plusieurs individus (Daujeard et al. 2017; Delagnes and Rendu 2011; Gaudzinski 1995; Magniez and Boulbes 2014; Rendu 2010; Rendu et al. 2012).

L'appréhension des groupes humains à partir des techniques bouchères est une approche beaucoup moins développée. Récemment, des études sur les stries de découpe et les stigmates de fracturation des os longs au Paléolithique moyen au Proche-Orient et en Europe occidentale ont permis d'identifier des techniques de découpe standardisées et des traditions bouchères propres à un même groupe, impliquant dès le Paléolithique moyen la transmission des savoir-faire et une éventuelle spécialisation des tâches pour la gestion des carcasses (e.g., Blasco et al. 2013; 2019; Castel et al. 2017; Fiorenza et al. 2015; Pobiner et al. 2018; Soulier and Costamagno 2017; Stiner et al. 2011).

1. 2. 2. Perspectives historiques et méthodologiques de la fracturation osseuse

Les restes fauniques font partie des rares vestiges qui nous sont accessibles pour comprendre et proposer des hypothèses sur les comportements de subsistance des hominines pour les périodes anciennes du Paléolithique. Dès le début du vingtième siècle, des chercheurs ont tenté de comprendre les raisons de la présence de nombreux fragments et éclats osseux dans les assemblages fauniques (Black et al. 1933; Breuil 1938; Breuil and Boyle 1939; Martin 1910; Pei 1938). De nombreuses études expérimentales ont permis d'appréhender les différents processus de fracturation des os et d'identifier les divers agents taphonomiques qui pouvaient en être la cause. L'intérêt, en contexte archéologique, était de pouvoir distinguer les hominines des autres agents. Dans cette optique, l'identification des raisons qui expliquent la fracturation des os s'est révélée essentielle. Deux hypothèses ont ainsi été avancées : l'extraction de la moelle osseuse et la fabrication des outils en os (Bonnichsen 1979; Breuil 1938; Dart 1957; 1960; Dauvois 1974; Martin 1910; Morlan 1979; 1980; Noe-Nygaard 1977; Pei 1939; 1938; Poplin 1973; 1978). Pour les distinguer, des travaux ont tenté de mettre en évidence des schémas de fracturation, mais sans

tout le temps parvenir à discriminer les agents (Alhaique 1997; Boulestin 1998; Johnson 1985; Moclán et al. 2019; Outram 2001; 2005; Pickering et al. 2005).

Au milieu des années 1980, les observations éthologiques et ethnographiques confirment que les hominines, tout comme certains carnivores, peuvent accumuler des ossements et les fracturer quasi-systématiquement pour consommer la moelle. Certains auteurs notent que ces deux types d'accumulateurs peuvent produire des fractures hélicoïdales similaires (i.e., Washburn 1957; Miller 1975; Hill 1976; Bonnichsen 1979; Binford 1981; Brain 1981; Haynes 1982; Haynes and Stanford 1984; Gonzales 1991). Les preuves s'accumulent et mettent en évidence que les hominines et les carnivores pouvaient occuper les mêmes sites et créer des accumulations « mixtes » (e.g., Potts and Shipman 1981; Brain 1981; Blumenschine 1986; Bunn et al. 1986; Hill 1989; Cavallo and Blumenschine 1989; Blumenschine and Selvaggio 1991; Bunn 1991; Marean et al. 1992; Blumenschine and Marean 1993; Selvaggio 1994; Capaldo 1995, 1997; Blumenschine et al. 1996). Ces palimpsestes d'occupations mixtes peuvent rendre difficile l'identification du ou des accumulateurs des ossements fracturés. Le piétinement, tout comme le charriage ou la chute de bloc peuvent également provoquer des fractures supplémentaire des os (Behrensmeyer et al. 1989; Dauvois 1974; Griggo 2013; Oliver 1989). Le contexte environnemental peut lui aussi jouer un rôle prépondérant dans la fragmentation osseuse, la température, le taux d'humidité ou encore le poids des sédiments fragmentant aussi les ossements. Cependant, dans ces cas-là, les profils de fractures sont différents, du fait de l'état sec de l'os lors de la fragmentation. Des critères ont été définis pour différencier les fractures peri-mortem (fractures sur os frais) de celles post-dépositionnelles (fractures sur os sec) (Haynes 1983; Johnson 1985; Morlan 1984; Outram 2000; 2001; 2002; Villa and Mahieu 1991). L'enjeu a été ensuite d'établir des critères pour identifier le ou les agents à l'origine de la fracturation. Cela a été permis principalement par la présence de modifications de surfaces associées caractéristiques telles que des marques de dents, de percussion ou des stries de boucherie. De nombreux travaux expérimentaux et ethnographiques ont définis des critères pour identifier les traces de carnivores et humaines (e.g., Arriaza et al. 2018; Blumenschine 1995; Capaldo 1997; Domínguez-Rodrigo et al. 2009; Fourvel 2012; Galán et al. 2009; Lupo and O'Connell 2002; Maté-González et al. 2016; Parkinson et al. 2014; Pineda et al. 2014; Saladié et al. 2013; Yravedra et al. 2018)

En parallèle, les études ethnographiques ont ouvert de nouvelles perspectives pour étudier les comportements des groupes humains passés (Delpech and Rigaud 1974; 1977; Poplin 1973; Teleki 1975). Binford (1978, 1981) a par exemple mis en évidence des schémas de

fracturation d'extraction de la moelle chez les Nunamiut en Alaska (Etats-Unis). Il a ainsi observé que les coups n'étaient pas portés aléatoirement, mais à des emplacements spécifiques et ce parfois de manière systématisée. Au sein d'un groupe, il est donc apparu possible d'identifier des pratiques traditionnelles d'extraction de la moelle pouvant varier d'un groupe à l'autre. Par conséquent, les marques de percussion observées dans un assemblage faunique ne permettraient plus seulement de distinguer une accumulation humaine d'une accumulation de carnivores, mais pourraient aussi permettre d'identifier de possibles traditions bouchères.

Dans ce manuscrit nous entendons faire la différence entre un schéma de distributions des marques de percussion systématiques et standardisées : dans le premier cas, les traces sont systématiquement localisées au même endroit sur la diaphyse de l'os long alors que dans le second cas, des traces ont été enregistrées sur plusieurs zones de la diaphyse mais elles sont plus nombreuses à certains emplacements, montrant des zones frappées préférentiellement ou des tendances.

1. 2. 3. Identifier des traditions bouchères

Blasco et al (2013) ont démontré la présence de traditions bouchères dès le Paléolithique moyen à partir de l'analyse de la distribution des marques de percussion sur les diaphyses d'os longs en comparant deux sites espagnols du Paléolithique moyen ancien et récent, Bolomor (levels IV, IX, Xlla and Xllc, région valencienne) et Gran Dolina (TD10-1, région Castille-et-Léon) (MIS 5-9) (Blasco et al. 2013). Le niveau IV du site de Bolomor a révélé une systématisation des pratiques de récupération de la moelle dans un groupe et même une transmission intergénérationnelle de ces pratiques et le retour du même groupe sur le site au cours du temps. En revanche, pour le niveau 10-1 de Gran Dolina, les auteurs suggèrent des occupations brèves par plusieurs groupes humains porteurs de pratiques différentes. Les niveaux archéologiques fouillés représentent généralement des palimpsestes d'occupation et les assemblages fauniques de ces niveaux résultent donc de plusieurs occupations dont il est complexe d'estimer le nombre et la durée (Bailey 2007; Gabucio et al. 2018; Lucas 2008).

L'activité bouchère de fracturation des os pour en extraire la moelle peut dans certains cas permettre la distinction de comportements traditionnels chez les Néandertaliens. Par exemple, une répartition standardisée et contre intuitive des marques de percussion sur les diaphyses des os longs peut démontrer la présence de pratiques standardisées employées par des individus d'un même groupe. Ces marques de percussion sont donc à considérer comme de bons indicateurs pour mettre en évidence des traditions bouchères en contexte archéologique. Elles

résultent d'une action directe et volontaire sur les ossements. Les stries de boucherie, au contraire, sont des épiphénomènes laissées accidentellement sur les os (Binford 1981; Lyman 1994; Soulier and Costamagno 2017; Valensi 1991). Leur intensité, leur fréquence et leur nombre résultent surtout de la dextérité et des compétences du boucher, de la morphologie et de la taille de l'animal, ou encore des types de matières premières des outils de découpe.

Les Néandertaliens ont fracturé quasi systématiquement les os longs d'herbivores pour récupérer la moelle. Au sein de ces groupes, certains individus auraient donc pu développer des compétences spécifiques dans le traitement des carcasses, et dans cette activité plus particulière, tout en transmettant leur savoir-faire d'une génération à l'autre (Blasco et al. 2013; Merritt and Davis 2017; Moclán and Domínguez-Rodrigo 2018; Pickering and Egeland 2006; Vettese et al. 2017). La présence de traditions bouchères dans un groupe impliquerait des savoir-faire particuliers (une connaissance de la séquence précise de gestes), le dévouement investi dans la tâche de récupération de moelle (le temps investi dans l'activité) et des compétences développées (l'habilité à reproduire des gestes et corriger ces erreurs) (Forte 2019). Considérant les pratiques socio-culturelles des groupes néandertaliens comme un tout, l'étude des traditions bouchères doit être mise en perspective avec celles des stratégies cynégétiques et des traditions culturelles techniques dans un site.

*Approche techno-culturelle de la fracturation des os longs chez les Néandertaliens (Sud-Ouest de l'Europe, MIS 5-3) :
une systématisation des gestes ?*

I. 3. Organisation de la thèse

Le présent manuscrit est une thèse sur articles et regroupe à la fois des manuscrits en anglais et en français. Ces articles sont déjà publiés, sous presse ou seront soumis très prochainement. La thèse s'organise autour de cinq chapitres dans lesquels nous avons inclus les différents articles. Ces derniers sont présentés par une fiche d'identité, regroupant titre, auteurs et résumé en anglais, ainsi que par un résumé long en français.

Dans **le chapitre I**, nous avons énuméré brièvement les principales questions et problématiques qui ont motivé ce travail, nous avons fait un bref état de l'art sur le sujet, et enfin nous présentons la structure de la thèse.

Le chapitre II est dédié à la présentation du matériel d'étude et des méthodes employées dans ce travail. Nous présenterons l'approche archéozoologique utilisée pour analyser le matériel, ainsi qu'un travail plus particulier concernant les marques de percussion, représentant sur la **publication n°1** : « *Towards an understanding of hominin marrow extraction strategies: a proposal for a percussion mark terminology* ». Ce travail a permis de clarifier la nomenclature des marques de percussion en proposant une terminologie descriptive des marques de percussion proprement dites que nous opposons aux marques consécutives à la fracturation et aux stries liées à la percussion. L'ensemble de ce travail de recherche repose sur l'identification et la caractérisation précise des marques de percussion *sensu stricto*. Il est le résultat d'une collaboration entre des chercheurs de plusieurs nationalités.

Le chapitre III présentera les différents travaux expérimentaux de fracturation des os longs. Après avoir détaillé le protocole de la vaste expérimentation que nous avons effectuée pour explorer les manières intuitives de récupérer la moelle osseuse, nous présentons quatre études issues des données expérimentales récoltées. Premièrement, la communication réalisée au Vème Congrès International d'Archéologie Expérimentale (Tarragone, octobre 2017) : « *Between intuitiveness and standardization: an experimentation on marrow extraction process* » présenterons les résultats d'une étude sur la localisation du premier coup et des facteurs qui peuvent influencer sa position lors de la récupération de la moelle. A l'aide de la **publication n°2** : « *A GIS based approach to long bone breakage patterns derived from marrow extraction* » aborde l'analyse de la distribution des coups sur le matériel expérimental selon de nouvelles approches méthodologiques basées sur l'analyse spatiale SIG (Système d'Information Géographique). Dans la **publication n°3** « *A way to break bones? The weight of intuitiveness* » nous analyserons la distribution des marques de percussion sur les os longs en contexte intuitif. Cette distribution a

été analysée à l'aide de la méthode mise en place pour la **publication n°2**. Nous avons pu mettre en évidence la présence d'un schéma de répartition intuitif des traces et identifier les variables pouvant l'influencer, dont celles liées à l'expérimentateur ou encore à la morphologie des éléments osseux. Enfin, dans ce chapitre, nous résumons les apports d'une autre expérimentation réalisée au cours d'un Master 2 par L. Chevillard (co-encadrement) qui s'est intéressée au lien entre le geste effectué lors de la fracturation et les traces produites « Du geste au stigmaté : l'apport de l'expérimentation à la caractérisation des impacts de percussion en contexte archéologique ».

Dans **le chapitre IV**, nous présenterons l'analyse des marques de percussion au sein d'assemblages de faunes fossiles provenant de trois sites du Paléolithique moyen du Sud-Ouest de l'Europe : L'Abri du Maras, la grotte de Saint-Marcel (Ardèche, France) et Riparo Tagliente (Vérone, Italie). La **publication n°4** s'est intéressée au seul niveau 4.1 de l'Abri du Maras et est le résultat en partie de travaux de Master (Vettese, 2014) : « *Neandertal long bone breakage process: standardized or random patterns? The example of Abri du Maras (Southeastern France, MIS 3)*. » Dans la continuité de ce premier travail, la **publication n°5** intègre une étude comparative des trois sites archéologiques, ainsi que des données expérimentales : « *New evidence of butchery traditions within the Neandertal groups occupying Southwestern of Europe* ». Ce dernier article est le cœur de la thèse, et tente de répondre à la question de l'existence ou non de traditions bouchères chez Néandertal via la distribution des marques de percussion. C'est une synthèse des principaux travaux effectués au cours de cette thèse.

Enfin, **le chapitre V** correspond à la conclusion de cette thèse, faisant le bilan de l'ensemble des résultats, tout en ouvrant des perspectives.

Les annexes du manuscrit regroupent les articles publiés, les « Supplementary data » (Annexes 1 à 4), ainsi que la **publication n° 6** (Annexe 5).

Chapitre II.

Matériel et méthode

*Approche techno-culturelle de la fracturation des os longs chez les Néandertaliens (Sud-Ouest de l'Europe, MIS 5-3) :
une systématisation des gestes ?*

II. 1. Matériel

Dans ce travail de recherche, le matériel faunique a été analysé dans l'optique d'identifier et de caractériser des pratiques bouchères spécifiques aux groupes, qui se sont succédés, dans les différents sites archéologiques. Pour cela, nous nous sommes intéressées plus particulièrement à la distribution des marques de percussion sur les os longs d'herbivore. En effet, ces derniers, contrairement aux éléments osseux du squelette axial et des os courts, ont des quantités de moelle osseuse les plus élevées, avec un « *Modified General Utility Index* » compris entre 28 et 100 (Binford 1978). Ces éléments de la carcasse sont donc quasi-systématiquement fracturés par les hominines et par les Néandertaliens, par exemple, pour en extraire la moelle jaune. Dans le cadre de cette étude, seuls les os longs déterminés au moins anatomiquement ont donc été pris en compte.

Le matériel de notre étude comprend deux principaux ensembles : le matériel expérimental et le matériel archéologique (Tableau 1 et 2).

Eléments	N° Individu	NRDa	NRI	NRT
Fémur	3	130	129	259
Fémur	5	137	65	202
Fémur	8	113	109	222
Humérus	1	109	181	290
Humérus	7	77	54	131
Humérus	11	84	111	195
Radio-ulna	2	119	144	263
Radio-ulna	9	80	33	113
Radio-ulna	12	73	116	189
Tibia	4	192	247	439
Tibia	6	120	55	175
Tibia	10	166	78	244
	Total	1400	1322	2722

Tableau 1: Nombre de restes étudiés pour l'expérimentation (NRDa: Nombre de Restes Déterminés Anatomiquement, NRI : Nombre de restes indéterminés, NRT : Nombre de restes total).

Le matériel expérimental rassemble à la fois l'ensemble des observations enregistrées durant l'expérimentation et les données répertoriées durant la phase d'analyse des ossements en laboratoire. L'échantillon expérimental compte 368 os longs de vache réformée (anciennes vaches laitières), dont 93 radio-ulnas, 95 humérus, 90 fémurs et 90 tibias. Ces ossements ont été fournis par l'entreprise Charal et proviennent de l'abattoir de Cholet (Maine-et-Loire). Aucun métapode n'a pu être récupéré pour cette expérimentation car ils sont coupés à la pince durant le traitement boucher en amont. Parmi ce lot, 120 éléments ont été sélectionnés pour l'analyse, 30 pour chaque

type d'os long, afin d'avoir des échantillons statistiquement significatifs. Le nombre final de restes fracturés étudiés s'élève à 2722 restes, dont 1400 restes déterminés (Tableau 1). Le nombre restant correspond aux fragments dits indéterminés, c'est-à-dire ne comprenant aucune particularité morphologique permettant de les identifier après fracturation. Il s'agit généralement des plus petits éléments. Une partie des ossements analysés, 40 éléments (10 humérus, 10 radio-ulna, 10 fémurs et 10 tibias) a servi à développer un protocole d'analyse spatiale par SIG (voir Stavrova et al. 2019).

Le nombre de restes archéologiques étudiés est de 2187 restes d'os longs, dont 254 humérus, 333 radio-ulnas, 211 fémurs, 555 tibias, 228 métacarpes, 439 métatarses et 167 métapodes indéterminés. Ils se répartissent inégalement selon les sites et les niveaux (Tableau 2). Les niveaux d'occupation étudiés pour chacun des sites sont sub-contemporains (MIS 5-3) et correspondent tous à des phases d'intenses activités humaines, avec des processus complets de traitement des carcasses *in situ* (Publication n°5). Les niveaux de Saint Marcel et de l'Abri du Maras ont été fouillés en extension. Cependant, les niveaux moustériens de Riparo Tagliente proviennent d'une tranchée et d'un sondage effectués à la fin des années soixante-dix et au début des années quatre-vingt (1978 à 1980) avec la fouille de quatre carrés supplémentaires pour le niveau 35 en 2002.

Site	Abri du Maras			Sait-Marcel		Riparo Tagliente		Exp. Int.	NRDa Total
	4.1	4.2	4.2	g	H	35	37		
Taille	MONG	LONG	MONG	MONG	MONG	PONG	PONG		
NRDa Hum	97	32	41	18	30	18	18	270	524
%NRDa Hum	18.51%	6.11%	7.82%	3.44%	5.73%	3.44%	3.44%	51.53%	
NRDa Rau	123	29	79	41	43	5	13	272	605
%NRDa Rau	20.33%	4.79%	13.06%	6.78%	7.11%	0.83%	2.15%	44.96%	
NRDa Fem	45	29	32	32	36	15	22	380	591
%NRDa Fem	7.61%	4.91%	5.41%	5.41%	6.09%	2.54%	3.72%	64.3%	
NRDa Tib	184	93	95	64	60	20	39	478	1033
%NRDa Tib	17.81%	9%	9.2%	6.2%	5.81%	1.94%	3.78%	46.27%	
NRDa Metc	58	6	23	31	45	32	33		228
%NRDa Metc	25.44%	2.63%	10.09%	13.6%	19.74%	14.04%	14.47%		
NRDa Mett	167	8	72	47	76	39	30		439
%NRDa Mett	38.04%	1.82%	16.40%	10.71%	17.31%	8.88%	6.83%		
NRDa Metp	68	6	25	25	13	9	21		167
%NRDa Metp	40.72%	3.59%	14.97%	14.97%	7.78%	5.39%	12.57%		
NRDa Total	742	203	367	258	303	138	176	1400	3587
% NRDa Total	20.69%	5.66%	10.23%	7.19%	8.45%	3.85%	4.91%	39.03%	

Tableau 2 : Matériel archéologique et expérimental étudié (hum : Humérus, rau : Radio-ulna, fem : Fémurs, tib :Tibia, metc : Métacarpe, mett : Métatarse, metp : Métapode, NRDa : Nombre De Restes Déterminé Anatomiquement, NRDa tot : Nombre De Restes Déterminé Anatomiquement Total, PONG : petit ongulé, MONG : Moyen ongulé, GONG : Grand ongulé , Exp. Int. : Expérimentation sur l'intuitivité.

II. 2. Méthode

II. 2. 1. Détermination et quantification

II. 2. 1. 1. Détermination et enregistrement des données

La détermination des restes (os longs) de notre échantillon a été faite, lorsque cela fut possible, jusqu'au rang spécifique. Dans le cas contraire, les vestiges fauniques ont été attribués à des classes de poids et taille (Tableau 3). Les os longs, en particulier les restes diaphysaires, ne sont pas toujours déterminables au rang de l'espèce surtout dans les sites dans lesquels elles ont des tailles et des poids similaires (e.g. chamois et chevreuil). Par ailleurs, la structure osseuse (i.e. épaisseur corticale, taille des diaphyses...) peut être très proche pour des espèces de même classe. Pour comparer les assemblages étudiés, j'ai donc choisi de regrouper les restes d'os longs identifiés anatomiquement selon cette distinction en classe de taille et de poids. Nous avons différencié les adultes des juvéniles en prenant en compte le critère d'épiphyse des portions articulaires présentes. Les os longs fœtaux et néonataux, du fait de leur structure, ne contiennent pas de moelle jaune. Ils ont donc été exclus des échantillons d'étude.

Classes de poids des ongulés		
PONG	10-100 kg	Chevreuil, Chamois, Bouquetin
MONG	100-200 kg	Renne, jeune Cerf, Sanglier
GONG	200-1000 kg	Cheval, Bison, Aurochs, Mégacéros, Elan

Tableau 3 : Catégories de poids des ongulés présent dans notre échantillon d'étude, (d'après Saladié et al. 2011 et Patou-Mathis 1997).

Durant cette phase préliminaire d'identification des restes, je me suis appuyée sur les supports suivants :

- Des collections d'anatomie comparée : de l'Institut de Paléontologie Humaine (Paris, France), de l'Université de Ferrara (Italie) et de la Cité de la Préhistoire (Ornac, France).
- Des ouvrages de références : Hue 1907, Barone 1976, Lavocat, 1966 ; Pales & Lambert, 1971 ; Pales & Garcia, 1971 ; Pales & Garcia 1981.
- Des déterminations préalablement effectuées par des collègues paléontologues spécialistes : N. Boulbes pour les Equidés, N. Lateur pour les Cervidés et E. Crégut-Bonnoure pour les Bovidés et par des collègues archéozoologues : C. Daujeard, L. Chevillard et U. Thun Hohenstein pour les sites de la Grotte de Saint Marcel, de l'Abri du Maras et de Riparo Tagliente (Daujeard et al., 2017; Thun Hohenstein, 2001).

Dans le cadre de la procédure d'enregistrement de la localisation des marques de percussion les os longs ont été divisés comme suit, par portions : portion 1 : portion articulaire proximale, portion 2 : diaphyse proximale, portion 3 : diaphyse médiale, portion 4 : diaphyse distale, portion 5 : portion articulaire distale et par faces : face antérieure : face crâniale, face postérieure : face caudale, face latérale et face médiale. Une portion et une face associées définissent des zones (Saladié et al. 2011) (Figure 1).

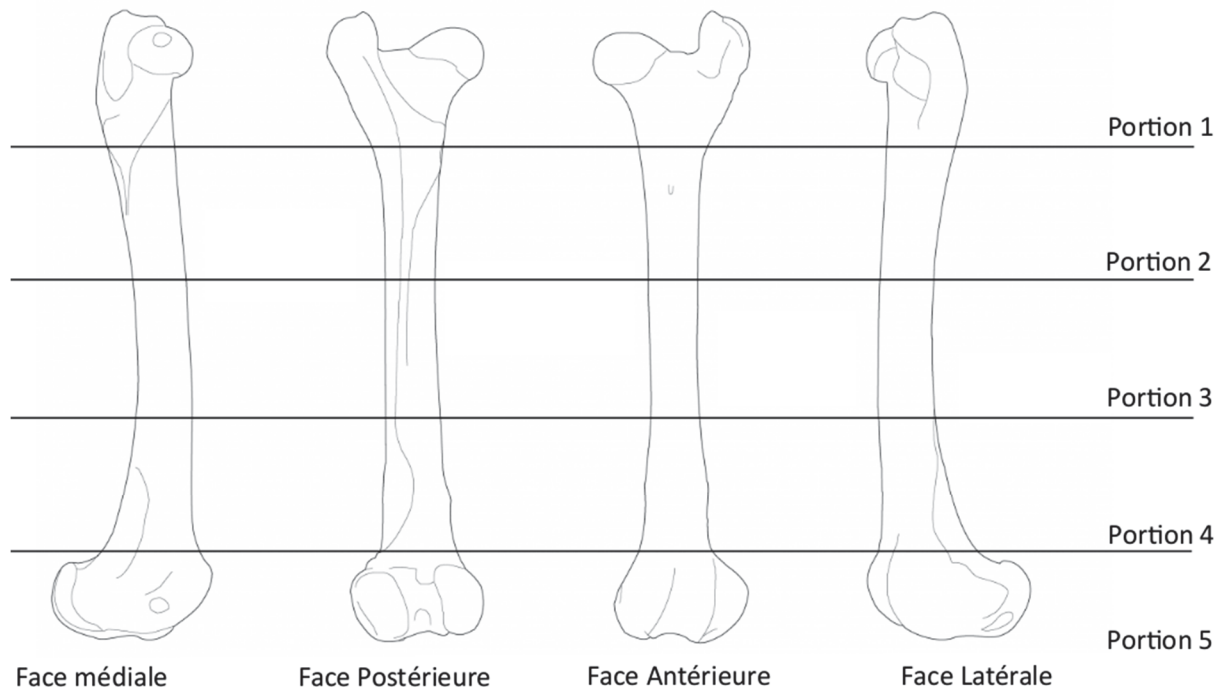


Figure 1 : Exemple de la nomenclature utilisée dans la description des faces et portions des os longs, ici un fémur de renne (d'après J.-C. Castel (Geneva Museum) - © 2013 archéozoo.org).

II. 2. 1. 2. Quantification

Les analyses archéozoologiques ont été effectuées à l'aide de différentes unités quantitatives et interprétatives, ainsi que d'un ensemble choisi d'index de quantifications (Lyman 1994).

Dans cette étude nous avons pris en compte les unités archéozoologiques quantitatives suivantes en les adaptant au contexte de l'étude :

- le Nombre de Restes (NR) ;
- le Nombre de Restes Déterminés taxonomiquement (NRDt) ;

- le Nombre de Restes Déterminés anatomiquement (NRDa) ;
- le Nombre de Restes Indéterminés (NRI), spécifiquement pour l'expérimentation, le NRI concerne les restes que nous n'avons pas pu remonter sur l'os ;
- le Nombre de Restes Total (NRT = NRI+NRDa) ;
- le Nombre Minimum d'Eléments (NME) calculé à partir des portions et des faces de chaque élément anatomique, en prenant en compte à la fois la latéralisation des éléments et l'âge (adulte ou juvénile), pour l'identification des catégories d'âge, nous avons pris en compte le degré d'épiphyse pour établir une catégorie adulte et une autre juvénile ;
- le Nombre Minimum d'Individus (NMI) de chaque espèce présente dans l'échantillon, calculé à partir du Nombre Minimum d'Individus de combinaison (NMIC) (prenant en compte l'âge et la taille) (Binford, 1981 ; Lyman, 1994). Nous avons aussi discriminé les os droits et gauches lorsque nous avons été en mesure de le faire. Le calcul des NME et NMIC a été facilité par la découpe virtuelle des os en différentes portions et faces (cf. ci-dessus).

Dans le cadre de l'analyse archéozoologique nous avons pris en compte :

- le rapport $\frac{\text{épiphyse}}{\text{diaphyse}}$ pour évaluer la fragmentation des assemblages fauniques ;
- l'Unité Animale Minimum (UAM) calculé à partir du Nombre Minimum d'Elément (NME) divisé par le nombre de cet élément présent dans le squelette (Binford, 1981 ; Lyman, 1994 ; Brugal et al. 1994) ;
- le pourcentage UAM des assemblages, avec UAMe : l'UAM de l'élément et l'UAMmax : l'UAM de l'élément le plus élevé de l'échantillon : $\frac{(UAMe)*100}{UAM\ max}$.

Le taux d'UAM représente l'abondance relative d'un élément (e). La corrélation entre le volume de la cavité médullaire des os longs et le UAM sera testée pour chacune des catégories de poids (Daujeard 2008, Blasco et al., 2013 et Vettese et al., 2017). Pour cela, nous avons considéré le volume de la cavité médullaire des os longs (en ml) proposé par Jones et Metcalfe (1988) pour les MONG, Binford (1978) pour les PONG et Outram et Rowley-Conwy (1998) pour les GONG.

Dans le cadre de l'analyse des marques de percussion, nous proposons les unités et indices suivants :

- le Nombre de Coups (NC) ;
- le Nombre de Marques de Percussion (NPM) ;
- la fréquence de zones présentes, qui est calculé à partir du NME et des zones définies précédemment (Figure 1) ;
- la fréquence des zones présentant au moins une marque de percussion directe par rapport au nombre total de zone présente dans chacun des échantillons d'étude ;
- la densité osseuse des os longs, proposée par Lyman (1994) et modifiée par Lam et al. (1999) établie par portion osseuse, que nous comparons à la fréquence de portion présente dans chaque échantillon.

II. 2. 2. Approche taphonomique

La taphonomie est un outil utilisé en archéozoologie pour comprendre les stratégies de subsistance de l'homme préhistorique. Les chercheurs utilisent depuis longtemps cette « science de l'enfouissement », et ce avant même qu'elle ait été clairement définie par Weigelt (1927) ou Efremov (1940) (Prunières 1868 ; Broca 1877 ; Martin 1907). Cet outil permet d'identifier les nombreuses modifications qui peuvent être observées sur les restes osseux fossiles, produites depuis la mort des animaux jusqu'à la découverte de leurs ossements à la fouille, et à leur étude en laboratoire (Figure 2). Grâce aux nombreux référentiels expérimentaux et archéologiques, il est possible de distinguer les modifications anthropiques de celles des autres agents biotiques et abiotiques. Pour l'identification des différentes modifications taphonomiques, nous nous sommes aidés des ouvrages et travaux suivants : Binford 1981; Lyman 1994 ; Denys et Patou-Mathis 2014 ; Fernandez-Jalvo et Andrews 2016. Ainsi, il est possible de mesurer l'impact des activités humaines sur les assemblages fauniques au sein des sites archéologiques. La taphonomie est basée sur l'actualisme, qui est, comme l'a défini Gifford-Gonzalez (2018), une approche méthodologique uniformitariste (principe hérité de la géologie, Whewell 1932). Par principe, on suppose que les phénomènes passés peuvent être expliqués par analogie aux phénomènes actuels, produisant des effets identiques. La taphonomie s'appuie à la fois sur l'expérimentation, l'ethnologie et l'éthologie pour définir des critères permettant d'identifier les effets produits par chacun des agents taphonomiques.

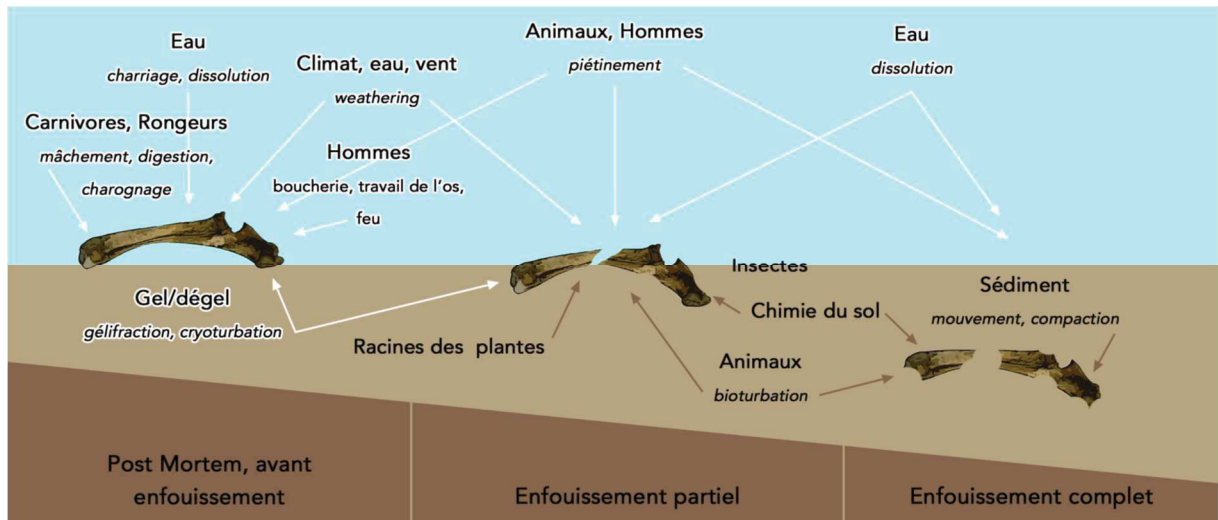


Figure 2 : Agents taphonomiques et processus (en italique) à l'origine des modifications osseuses (bleu : hors sol, marron : en sol), (illustration de L. Chevillard, 2018).

La première étape de notre analyse consiste donc à discriminer les marques qui ne sont pas liées à la récupération de la moelle. Dans cette optique, l'ensemble des échantillons a été analysé taphonomiquement. Une fois les différents agents modificateurs identifiés, nous nous sommes plus spécifiquement concentrées sur la fracturation osseuse et l'analyse des marques liées à la percussion.

Chacune des surfaces osseuses a été observée à l'œil nu sous une lumière rasante, à l'aide d'une loupe 15-20x et lorsque nécessaire, d'un stéréomicroscope (Leica S8 APO x10-80), pour caractériser et identifier les altérations taphonomiques de surface.

Les phénomènes taphonomiques naturels n'affectent pas tous les ossements de la même façon. Les os longs plus compacts sont mieux conservés dans les assemblages que les parties plus spongieuses telles que les vertèbres par exemple. De même, les différentes portions d'un os long ne sont pas affectées de la même façon. Par exemple, la diaphyse, compacte, résiste mieux aux aléas taphonomique que les articulations qui sont spongieuses. Les dents, quant à elles, sont parfois les derniers éléments conservés d'une carcasse. Ce principe de disparition non homogène des éléments est appelée conservation différentielle (Grayson 1989, Auguste 1994 ; Lyman 1994). Ce phénomène est notamment dû aux changements physico-chimiques des os opérés lors de la diagénèse. L'échantillon d'étude étant composé exclusivement d'os longs, la conservation différentielle n'a pu être testée que sur ces éléments notamment grâce au rapport entre le pourcentage UAM sur la densité osseuse.

Par ailleurs, les surfaces osseuses sont également différemment affectées par les divers agents taphonomiques naturels. Dans des cas extrêmes, les surfaces peuvent être entièrement

dissoutes ou concrétionnées jusqu'à les rendre illisibles. Pour considérer le degré de dégradation des éléments étudiés dans cette étude, j'ai classé les restes selon leur indice de lisibilité de surface : 0 la surface est illisible, 1/3 ou 2/3 de la surface est lisible et 1 la totalité de la surface est lisible (Daujeard 2008). Cet indice permet de prendre en compte la lisibilité des surfaces dans le décompte des marques bouchères et de carnivores. Une surface illisible ne sera pas prise en compte dans le calcul des proportions. Concernant les marques de percussion, certaines comme les encoches ou les enfoncements ne sont pas affectées par l'illisibilité des surfaces contrairement aux *pits* (*dépression*) ou aux *grooves* (*sillons*) qui se situent sur la corticale. Cet indice de lisibilité permet de ne pas sous-interpréter la présence des traces d'activités de boucherie. Grâce à ces indices, j'ai pu mettre en exergue l'importance de la perte d'informations dues aux phénomènes taphonomiques naturels selon les niveaux étudiés.

Par ailleurs, l'action des agents taphonomiques n'est pas uniforme sur les restes osseux. Elle peut varier beaucoup d'un site à l'autre, mais aussi au sein d'un même site ou d'un même niveau. De plus, un même agent taphonomique peut produire divers types de modifications et plusieurs agents peuvent avoir des actions semblables (équifinalité). Pour que l'enregistrement des données soit le plus objectif possible, j'ai choisi dans la continuité du travail de Daujeard (2008) d'enregistrer le degré d'envahissement de chaque modification physico-chimique sur la surface corticale. Le code utilisé va de 0 (surface non-altérée) à 3 (surface totalement altérée). Dans la suite, les échelles définies pour l'enregistrement des données ont été notées à côté de l'agent modificateur.

Il existe de nombreuses façons de présenter les divers types de dégradations taphonomiques. J'ai choisi, en rapport avec ma problématique de recherche, de les classer par agents. La méthode que nous présentons dans cette partie s'inscrit dans la continuité du travail de Daujeard (2008) effectué pour les sites de l'Abri du Maras et de la grotte de Saint Marcel (niveaux g et h). Dans un premier temps, seront présentés les effets des agents abiotiques ou climato-édaphiques, puis ensuite les agents biotiques non-humains en terminant par les agents humains. Enfin, une dernière partie s'intéressera plus particulièrement aux marques de percussion dues à l'extraction de la moelle jaune des os longs.

II. 2. 2. 1. Agents climato-édaphiques

Le weathering ou intempérisation (f0-f3) ; (d0-d3)

Le *weathering* ou intempérisation (traduction de Poplin, 1976) correspond aux différents processus de décomposition naturelle des os avant et après son enfouissement total. De ce processus, sont exclus : l'action des carnivores, le piétinement, le transport fluvial (Behrensmeyer 1978). La destruction des restes osseux varie en fonction de la température, des intempéries, de l'humidité, de l'aridité, etc. A partir des observations issues d'une expérimentation menée dans les savanes du Kenya (bassin d'Amboseli), Behrensemeyer (1978) a défini six stades de destruction enregistrés en fonction de la durée d'exposition des ossements à l'intempérisation. Cependant, comme le souligne Lyman (1994), ces données ne sont pas transposables dans l'absolu au contexte glaciaire et périglaciaire des niveaux étudiés ici. En effet, selon le contexte climatique, la vitesse d'apparition des différents stades varie. Malgré tout, l'avancée relative des stades d'intempérisation permet à la fois d'évaluer le temps d'exposition à l'air libre, d'envisager des apports successifs de carcasses, et d'appréhender la périodicité des occupations.

L'intempérisation affecte les ossements selon deux principales altérations visibles en surface : la fissuration (f0 à f3) et la desquamation (d0 à d3). Il est à noter que selon l'élément squelettique considéré, la taille et l'âge des individus mais aussi selon l'espèce, l'intensité et la localisation des modifications peuvent être différentes (Tappen, 1976 ; Behrensmeyer, 1978 ; Gifford, 1981). Les effets de l'intempérisation ont été enregistrés selon la méthode suivante (d'après Behrensmeyer, 1978 ; modifié par Daujeard, 2008) :

- Stade 0/1 : f0 et d0 ;
- Stade 1 : f1 et d0, apparition de la structure fibreuse de l'os ;
- Stade 2 : f1-f2 et d0-d1, écaillage et craquelure de la surface ;
- Stade 3 : f2 et d1, surface rugueuse et fibreuse ;
- Stade 4 : f2-f3 et d2, apparition d'esquilles, ouverture des craquelures, desquamation de la surface ;
- Stade 5 : f3 et d3, détachement des esquilles, fragmentation longitudinale suivant les fissures naturelles provoquées lors des stades antérieurs.

L'action éolienne (e0-e3)

L'action prolongée du vent sur les os provoque l'abrasion de la surface osseuse. Selon Shipman (1981) quatre stades d'émoussé des arrêtes sont provoqués par l'abrasion par le

vent : de e0, défini par l'absence d'éroussé, jusqu'au stade e3 où la surface osseuse est totalement éroussée.

L'action du sédiment (e0-e3) ; (f0-f3) ; (s0-s3)

Le sédiment encaissant peut contribuer à altérer les restes osseux de différentes manières. Tout d'abord, de par sa densité, il peut compacter les os et les fracturer. Les particules sédimentaires peuvent érousser les surfaces et les arêtes. Selon le pH du sol, les surfaces peuvent être dissoutes, parfois jusqu'à complète disparition de l'os en sol très acide (Auguste 1994). Dans ce cas, les trois stades de dissolution des surfaces osseuses sont notés s3 lorsque la surface est entièrement dissoute, et s0 lorsqu'elle ne l'est absolument pas. Le remaniement du sédiment peut aussi être à l'origine de la dégradation des ossements et de leur perturbation dans l'espace.

L'action du gel (f0-f3)

En milieu glaciaire et périglaciaire, l'alternance gel/dégel provoque un type de fissuration/délitement caractéristique, dit en « pile d'assiettes » (Guadelli 2008). Cette fissuration se fait dans l'épaisseur de la cortical desquamant une couche après l'autre et pouvant révéler un feuilletage des couches osseuses. On peut également remarquer une fissuration selon l'axe vertical de la diaphyse, créant des « bâtonnets ».

L'action de l'eau (e0-e3) ; (f0-f3) ; (d0-d3) ; (s0-s3) ; (c0-c3)

L'action de l'eau sur les restes fauniques peut être de deux ordres : une action de transport avant l'enfouissement (ou lors d'une réexposition du matériel à l'air libre) et une action corrosive. Son action sur un assemblage osseux peut être aussi liée aux sédiments encaissants. Les altérations observées en surfaces les altérations mécaniques telles que la desquamation, l'éroussement des arêtes, la fissuration et la présence de stries (pouvant être confondue avec celles provoquées par le piétinement) et les altérations chimiques telles que la dissolution et les concrétions (Shipman 1977, Brugal 1994). Selon la méthode de Daujeard (2008) quatre stades ont été définis selon l'envahissement des concrétions : sur les surfaces de l'os, son absence étant le stade c0 et la couverture totale de la surface c3.

Le transport des ossements par l'eau est à l'origine de redistributions spatiales des os et parfois de la perte de certains éléments osseux. Les éléments tels que la tête, les os longs ou les

os court n'ont pas la même densité et n'offrent pas la même résistance à l'action de l'eau. Certains os, de par leur densité et leur composition physique (*compacta* et *spongiosa*) sont entraînés plus ou moins facilement et rapidement transporté par l'eau (cf. classement de Voorhies, 1969). La concentration dans un même lieu du matériel archéologique et/ou l'orientation préférentielle des os longs sont des signes d'un transport par l'action de l'eau. Au contraire, des connexions anatomiques encore en place et une distribution aléatoire peuvent indiquer l'absence ou une très faible influence de cet agent.

La coloration de la surface osseuse (m0-m1) ; (o0-o3)

Des colorations de différentes teintes de la surface osseuse ont été enregistrées. Au sein d'un site et parfois même d'un même niveau, ces colorations peuvent varier, révélant une histoire taphonomique différente des restes selon la zone d'enfouissement.

Nous avons enregistré deux types de colorations différentes sur la surface des restes osseux : une coloration noire (m0 représentant l'absence de coloration et m3 la coloration de la totalité de la surface osseuse), une coloration orangée (o0 la surface ne portant pas de trace orange et o3 la surface totalement recouverte d'orange). Dans le cas d'une coloration atypique, nous l'avons enregistrée dans nos observations. Ces colorations peuvent être dues à des dépôts ferreux ou organiques.

II. 2. 2. Agents biologiques non-humains

La vermiculation (v0-v3)

La vermiculation est l'action des racines sur les restes osseux. Ces dernières peuvent tracer sur les os des motifs sinueux à fond plat ou à section en U (Binford 1981). Ces réseaux sont peu profonds et lisses. Ils altèrent les surfaces des ossements et dans les cas extrêmes, ils empêchent leur lisibilité. Quatre stades d'altération ont été définis : du stade v0 caractérisé par l'absence de vermiculation au stade v3 où la totalité de la surface est altérée par les racines.

L'action des carnivores

Les sites et niveaux étudiés dans le cadre de ce travail ont été sélectionnés pour la quasi-absence de traces de carnivore. Les stigmates de fracturation laissés sur les os longs par les

carnivores ou les hommes peuvent en effet être similaires (encoches ou *pits* de percussion ou de dent ou fracture en spirale, par exemple), pouvant représenter un biais dans l'analyse (Blumenschine et al. 1981, Dominguez-Rodrigo et al. 2007, Arriaza et al. 2018). Les marques associées présentes sur les ossements percutés, telles que les stries de boucherie ou les traces de dents, permettent parfois de déterminer l'origine des stigmates dans un assemblage faunique. Les traces de carnivores sont variées : *pits*, *punctures*, griffades, mâchonnement ou traces de dissolution dues à la digestion des os (e.g., Brain 1981, Haynes 1983, Blumenschine 1995, Boulestin 1999, Saladié et al. 2011, Fourvel 2012). Il est possible de trouver aussi des coprolithes ou encore des os appartenant à des carnivores. Les niveaux étudiés dans le cadre de ce travail ont été sélectionnés pour la quasi-absence de l'action des carnivores sur les assemblages osseux pour écarter les problèmes d'équifinalité des traces.

L'action des rongeurs

L'action des rongeurs se manifeste par des traces d'incisives plus ou moins grandes. Ces traces sont parallèles entre elles, sont peu profondes et ont une section en U (Fernández-Jalvo and Andrews, 2016).

II. 2. 2. 3. Agents biologiques humains et non humains

Le *trampling* ou piétinement

Le *trampling* ou piétinement est l'action d'écrasement et de déplacement du sédiment et du mobilier associé lors du passage d'hommes ou d'animaux. En se déplaçant, le sédiment agit sur les os comme un phénomène mécanique provoquant la fragmentation et le déplacement des restes osseux, l'abrasion et l'émoussement des surfaces osseuses et la création de fines stries superficielles pouvant être à tort confondues avec des activités de boucherie. Les stries résultant du piétinement peuvent toutefois se différencier des stries de boucherie en fonction de leur disposition et de leur tracé aléatoire sur les surfaces osseuses (Olsen et Shipman 1988 et Dominguez-Rodrigo 2009).

II. 2. 2. 4. Agents biologiques humains

La chauffe et la combustion des ossements

L'action du feu sur les ossements laisse des marques distinctes. L'os change de couleurs selon la température à laquelle il est exposé au feu, ainsi qu'en fonction du temps et de la teneur en oxygène du foyer. De plus, sa composition chimique est alors modifiée, notamment par l'évaporation de l'eau et la disparition des matières organiques qu'il contient. Enfin, on peut aussi observer un changement de forme de la diaphyse à de hautes températures, comme par exemple la torsion, la fissuration ou la fragmentation (i.e. Stiner et al. 1995, Théry et al. 2005, Dumouchel 2013, Lebon et al. 2015). Des fissures polygonales caractéristiques apparaissent à partir de 400°C. Les changements de couleur des os ont été enregistrés selon les stades définis par Stiner et al. (1995) (Tableau 4). L'enregistrement de la couleur des os brûlés permet d'estimer la température à laquelle les os ont pu être exposés. Par ailleurs, en observant le taux de restes spongieux présentant des traces de chauffe, l'hypothèse d'une utilisation des os comme combustible peut être ou non envisagée. La diagénèse des ossements et les changements chimiques qu'elle induit ne nous permettent pas ou difficilement d'indiquer l'état de fraîcheur des os lors de la chauffe ou de la combustion. Les transformations dues à l'exposition au feu affectent peu les marques laissées par les autres agents taphonomiques. Par exemple, les stries de boucherie ou les marques de percussion peuvent être encore lisibles sur les surfaces de l'os même après avoir été chauffées, carbonisées et même parfois calcinées.

La littérature scientifique propose différentes hypothèses pour expliquer les raisons de l'exposition des restes fauniques au feu dans un niveau archéologique (e.g. Brain 1981, Gifford-Gonzalez 1989, Caceres et al. 2002, Théry-Parisot and Costamagno 2005, Campmas 2012) :

- une exposition accidentelle : soit un feu accidentel atteint le site et les restes fauniques peuvent être chauffés, carbonisés ou calcinés, soit les restes sont localisés à proximité ou sous le foyer, pouvant être partiellement enterrés ;
- une utilisation du feu à des fins sanitaires : soit pour nettoyer les déchets culinaires ou pour repousser les carnivores et les empêcher de charogner la viande ;
- la cuisson de la viande : une exposition partielle des os qui sont à nus lors de la cuisson de la viande et donc une coloration hétérogène ou partielle des surfaces osseuses ;
- la chauffe des os longs pour récupérer la moelle : une élévation de la température de l'os avant fracturation pour en extraire plus aisément la moelle jaune ;
- une utilisation comme combustible : une alimentation directe du foyer, notamment avec les parties spongieuses du squelette.

Des foyers ou des traces de foyers sont présents dans tous les niveaux pris en compte dans cette étude. Leur présence montre, entre autre, une forte anthropisation dans les niveaux concernés. L'utilisation de l'os spongieux comme combustible est également un facteur additionnel à prendre en compte dans la conservation différentielle des restes fauniques des échantillons étudiés. Dans le cadre de notre étude, il faut envisager que les os longs aient pu être chauffés (mais non carbonisés) pour faciliter l'extraction de la moelle (Caceres et al. 2002). La chauffe n'est alors pas suffisante pour colorer ou fissurer les éléments, et il n'est donc pas aisé de mettre en évidence de telles pratiques.

Stades de chauffe	Descriptions	Couleurs	Stades simplifiés
0	Non-brûlé	Beige	0
1	Légèrement brûlé (carbonisation localisée < 50 %)	Brun	1
2	Fortement brûlé (carbonisation localisée > 50 %)	Brun/Noir	
3	Totalement carbonisé	Noir	2
4	Localement calciné (calcination localisée < 50 %)	Gris foncé/Noir	
5	Fortement calciné (calcination localisée > 50 %)	Gris clair/Blanc	
6	Totalement calciné	Blanc	3
7	Longuement calciné	Turquoise	

Tableau 4 : Stades de chauffe enregistrés pour les ossements brûlés (d'après Stiner et al., 1995, Costamagno 2009).

Les activités de boucherie

La chaîne opératoire complète de boucherie est bien connue et similaire pour tous les types d'herbivores, grands ou petits (Costamagno and David 2009). A partir des observations ethnologiques et de celles issues des expérimentations archéologiques, il a été mis en évidence que seules certaines activités laissent des marques sur les os (e.g., Noe-Nygaard 1977, Potts et Shipman 1981, Binford 1978, 1981, White 1992, Delpech et Villa 1993). A partir de ces traces, il est possible d'identifier les différentes étapes de traitement boucher d'une carcasse : éviscération, dépouillement, désarticulation, décarnisation, raclage du périoste, récupération des tendons et de la moelle. Deux grandes catégories de marques sont laissées sur les os : les marques liées à la fracturation des os pour en extraire la moelle et les stries de boucheries laissées par les outils lithiques (Lyman 1987). Les stries de boucherie ont été enregistrées lorsque l'état des surfaces le permettait. Chaque groupe de stries a été associé avec l'activité bouchère correspondante (e.g., Shipman et Rose 1983, Valensi 1991, White 1992, Soulier 2013). Les stries sont non seulement inféodées à une activité bouchère, mais également fortement liées à

l'anatomie de l'animal et à la dextérité du boucher. Le but étant la découpe des tissus mous, les stries sont donc seulement un épiphénomène et ne peuvent pas être considérées comme une action directe intentionnelle, à l'inverse des marques de percussion. Ainsi, il n'est pas (ou difficilement) possible d'identifier des pratiques traditionnelles à partir de leur étude (Soulier et Costamagno 2017 ; Blasco et al. 2013). Les marques de fracturation laissées lors de l'extraction de la moelle sont le résultats d'une action volontaire sur l'os. La localisation de ces traces de percussion est également moins inféodée aux contraintes anatomiques, notamment des tissus mous (Blasco et al., 2013). L'ouverture de la cavité médullaire est dictée à la fois par la morpho-structure de l'os et par la volonté de l'individu. Dans le cadre de cette étude, nous nous sommes donc focalisées en particulier sur les marques relatives à la percussion dans l'intention de récupérer la moelle jaune car elles peuvent constituer un meilleur reflet des pratiques bouchères (Blasco et al., 2013; Masset et al., 2016; Moclán and Domínguez-Rodrigo, 2018; Vettese et al., 2017) (Vettese 2014).

Les stries de boucherie

Pour identifier et caractériser les stries résultant des activités de boucherie, nous nous sommes appuyées sur les travaux de : (e.g. : Binford 1981, Valensi 1991, Lyman 1987, 1994, Daujeard 2008 et Dominguez-Rodrigo et al., 2009, Abe 2005, Costamagno et David 2009). Les actions bouchères répertoriées pouvant laisser des stries sur les ossements sont l'éviscération, le dépouillement, la désarticulation ou démembrement, la décarnisation, le désossement, l'extraction de la cervelle et de la moelle, l'extraction de la graisse des tissus osseux, la production du jus d'os, le raclage du périoste et l'enlèvement des tendons.

Les stries d'origine anthropique résultent quasi-exclusivement des activités de boucherie et du raclage des surfaces. Elles peuvent se différencier des stries dues à de l'abrasion naturelle (piétinements, sédiments, eau...) grâce aux critères suivants : leur morphologie (section en V et autres variables listées ci-dessous : cf. Dominguez-Rodrigo et al., 2009) ; leur localisation (proximité des insertions musculaires et tendineuses et de la peau), leur orientation par rapport à la diaphyse ou aux épiphyses (pour les os longs) et leur distribution (isolées, groupées) (Binford, 1981 ; Potts et Shipman, 1981 ; Dominguez-Rodrigo et al. 2009). La répartition de ces stries de boucherie répond à des nécessités techniques et anatomiques. Elles ne sont donc pas distribuées aléatoirement, contrairement aux stries créées par les autres agents taphonomiques.

On distingue deux ensembles de stries de boucherie : les stries de découpe et les stries de raclage. Leur morphologie sont différentes, permettant de les distinguer facilement (Figure 3 et

Figure 4). Les incisions sont créées par l'action du tranchant de l'outil parallèlement à la surface de l'os et les marques de raclage sont créées par le glissement du tranchant perpendiculairement à la surface de l'os (Lyman 2008).

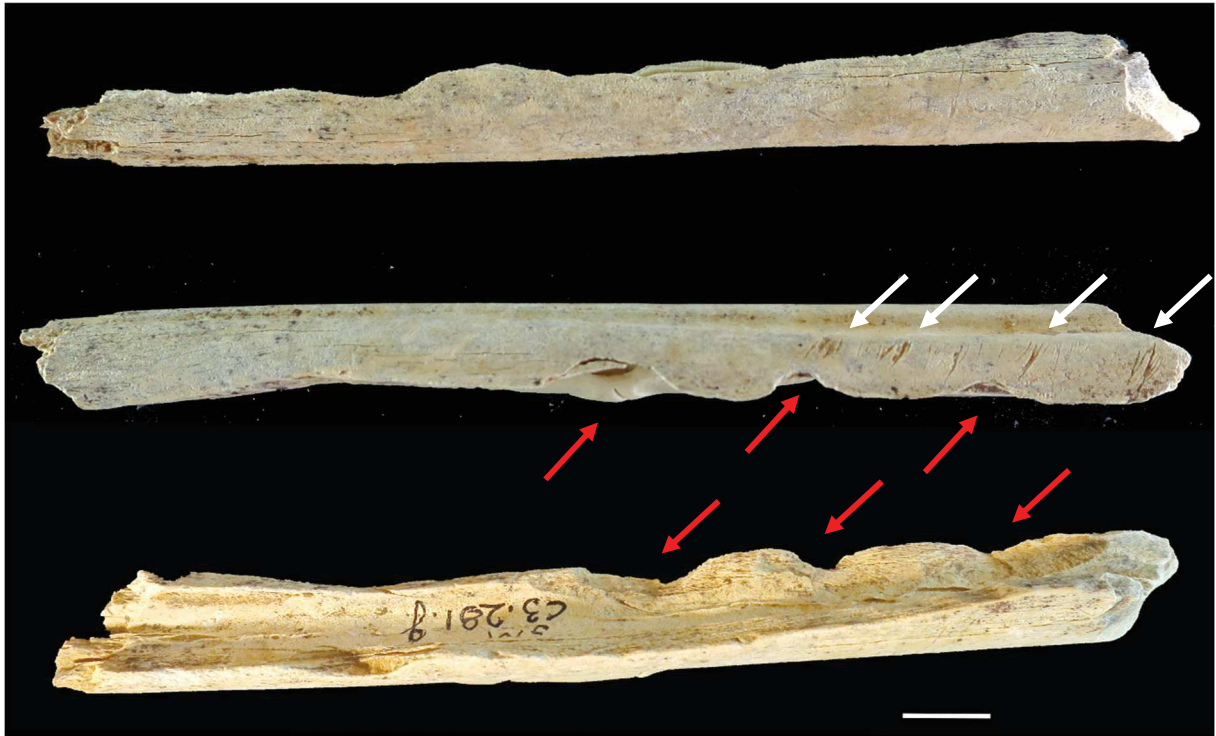


Figure 3 : Fragment diaphysaire de métatarse de chevreuil (PONG). Les flèches blanches indiquent les stries de découpe et les rouges les impacts de percussion. Provenance : niveau g de la grotte de Saint Marcel ; conservation : Citée de la Préhistoire, Orgnac, Ardèche (France) ; (échelle = 1cm ; cliché D. Vettese).

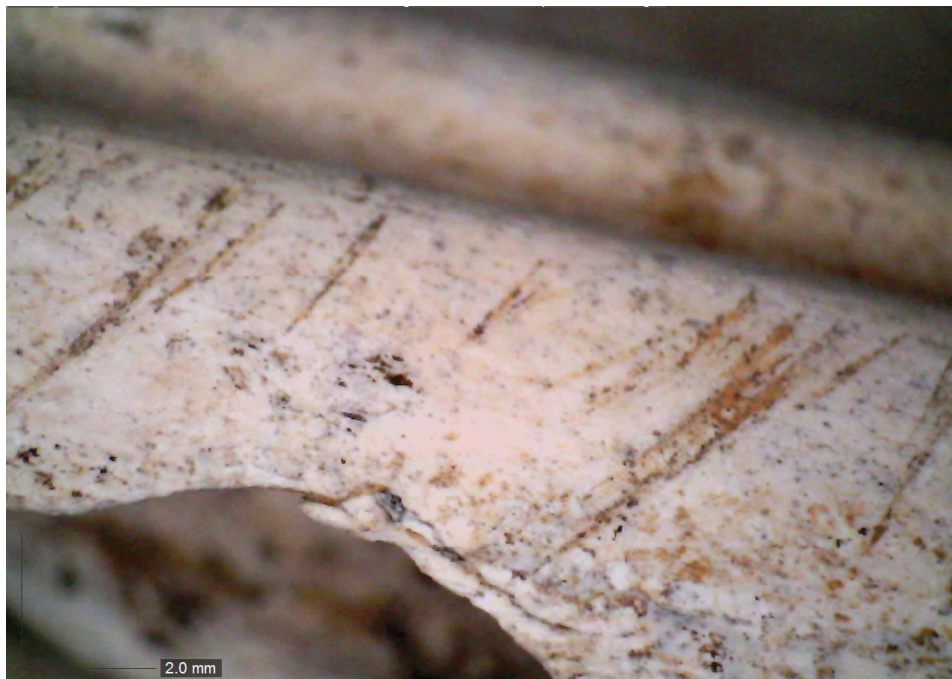


Figure 4 : Détail de stries et d'encoche avec à la fois un éclat adhérent et une sur-encoche sur un fragment diaphysaire du métatarse de chevreuil précédent (PONG) (échelle = 1cm ; cliché D. Vettese).

Plusieurs critères ont été enregistrés pour identifier et caractériser les ensembles de stries (Valensi 1991):

- le nombre de stries,
- leur longueur [courte (< 10 mm), moyenne (< 15 mm), longue (<20 mm et plus grande)],
- leur largeur [très fine, fine, épaisse (appréciation relative)],
- leur profondeur [superficielle, peu profonde, profonde (appréciation relative)],
- leur allure (droite, incurvée),
- leur localisation sur l'os (par zone et/ou à l'aide de caractère morphologique spécifique),
- la relation entre les ensembles de stries (superposé, intercalé parallèle, intercalé non parallèle),
- leur orientation par rapport au grand axe de l'os (parallèle, perpendiculaire, oblique),
- leur dispersion (groupé, isolé),
- la présence d'un dédoublement de ces stries (épaulement ou extrémité en fourche ou en barbe) ou d'une ou plusieurs microstriations internes.

Comme souligné plus haut, la lisibilité de la surface des os influe sur la lecture des marques de boucherie et notamment sur les stries. Les ossements « illisibles » n'ont pas été pris en compte dans les pourcentages du décompte des stries sur les os (Delpech et Villa 1993). J'ai aussi enregistré les relations de proximité entre les stries de raclage et les marques de percussion. En effet, le raclage du périoste peut servir à préparer l'os en vue de sa fracturation (Binford 1981). Dans ce cas, les stries de raclage ne sont pas directement inféodées à la morphologie osseuse. Ces stries peuvent alors nous informer sur la fréquence de cette pratique de préparation des surfaces osseuses, notamment dans le processus d'extraction de la moelle.

La fracturation

La fracturation est définie par le « fait de casser par un choc ou coup violent » (CNRTL). La fragmentation quant à elle est caractérisée comme « le fait de séparer en fragment » (CNRTL). La fracturation peut-être dans ce cas vu comme une sous-catégorie de la fragmentation, c'est-à-dire une fragmentation avec coup. Dans le cadre de ce travail, nous nous sommes focalisées sur la fracturation anthropique par percussion. Cependant, avant de m'intéresser plus précisément à la

fracturation, j'ai analysé en amont le degré et le type de fragmentation osseuse pour chacun des échantillons archéologiques et expérimentaux.

La longueur et la circonférence des diaphyses d'os long permettent de caractériser l'agent à l'origine de la fragmentation d'un assemblage faunique (Villa et Mahieu 1991). Dans cette optique, les fragments de diaphyse osseuse (> 40 mm) ont été divisés en quatre en fonction de la longueur diaphysaire initiale : avec $0 < L1 < 0.25 \leq L2 < 0.5 \leq L3 < 0.75 \leq L4 \leq 1$. La circonférence est quant à elle divisée en trois selon le rapport suivant : $0 < C1 < 0.5 \leq C2 < 1; C3 = 1$). Cette valeur varie selon la taille des herbivores. A l'aide de ce rapport de la longueur de la diaphyse en fonction de sa circonférence, il est possible par exemple de mettre en évidence une fragmentation d'origine anthropique dominée par une majorité de fragments de petite taille (L1) et de circonférence incomplète (<C3). Par contre, dans le cas d'une accumulation par des carnivores les auteurs remarquent un nombre plus grand de diaphyses avec une circonférence totale conservée en « cylindres » (Villa et Mahieu 1991). Leur travail met également en exergue l'importance de tenir compte de l'ensemble des éléments d'un assemblage osseux avant de pouvoir émettre des hypothèses sur les agents accumulateurs. Dans ce travail, j'ai dû sélectionner seulement les os longs déterminés. Cependant, ce rapport longueur/circonférence permettra de comparer l'intensité de la fracturation de chaque os long au sein des séries archéologiques et expérimentales.

La fracturation sur « os frais » opère peu de temps après la mort de l'animal. Lors de la diagénèse, la phase organique disparaît peu à peu pour laisser place à la phase minérale. Lors de ce processus, l'os perd peu à peu sa teneur en eau pour devenir « sec ». Du fait de ce changement physico-chimique, les fractures sur os sec ont une morphologie différente de celles sur os frais. Les critères mis en évidence par Villa et Mahieu (1991) permettent de discriminer les différents types de fractures sur os frais ou sur os sec. Les auteurs caractérisent trois critères morphologiques : l'angle, le profil et l'aspect des bords. Le plus souvent, une fracture sur os frais se caractérise selon les critères suivants : un angle oblique, un profil de fracture en spirale et enfin un aspect ou une texture lisse et non rugueux. La présence de critères parfois contradictoires sur un même bord de fracture m'a amenée à classer certaines fractures dans une catégorie de fracture indéterminée. Enfin, les fractures récentes causées par la fouille archéologique ou le conditionnement des restes (traitement post-fouilles) présentent une morphologie et une couleur de patine différentes des autres fractures, permettant de les distinguer aisément. Il est à noter que la présence de fissures sur les restes osseux n'est pas diagnostique d'une fragmentation peri- ou post-mortem.

La fracturation, comme mentionné précédemment, est une action violente de fragmentation. Cette action peut laisser des traces spécifiques sur les os. Cependant, la fracturation en vue d'extraire la moelle jaune ou la moelle rouge se distingue de par la structure de l'os qui les renferme. Dans le cas de la moelle jaune on y accède en ouvrant la cavité médullaire. Pour la moelle rouge, qui est localisée dans les articulations spongieuses possédant une structure alvéolaire, son extraction s'effectue à l'aide d'un concassage de ces parties (Morin and Soulier, 2017). Les études ethnographiques ont, en effet, mis en évidence la réduction des parties spongieuses en morceaux de plus ou moins grande taille pour extraire cette moelle rouge. Une fois réduite, la spongiosa peut être soit bouillie pour faire sortir la graisse, soit mâchée lorsqu'elle est écrasée en petits morceaux ou chauffée au soleil réduite en farine pour être conservée pour l'hiver (e.g. Binford 1978, Abe 2005, Costamagno et David 2009, Morin et Soulier 2017). La présence de petits fragments de spongiosa non brûlés au sein d'un niveau archéologique peut donc permettre d'identifier cette pratique (Lupo et Schmitt 1997, Outram 2001, Soulier 2013).

Exception faite des fractures et des fissures, de nombreuses autres marques sont liées à la fracturation et varient selon la structure même de l'os. Afin de faciliter la lecture de cette thèse, une sous-partie spécifique s'intéressant à la nomenclature de ces marques leur est dédiée. Cette approche a fait l'objet d'un article soumis à la revue : *Archaeological and Anthropological Sciences* (cf. Publication n°1, Chapitre. II.2.3. ci-dessous).

Les retouchoirs

Au sein des séries archéologiques étudiées, nous avons identifié plusieurs os longs portant des plages avec impressions (entailles, hachures, cupules, etc.) dites « de retouchoir » (Patou-Mathis et Auguste 2002) (Figures 5). Ces retouchoirs ont fait l'objet d'un enregistrement spécifique selon les méthodologies mises en place par Mallye et al. (2012) et par Daujeard et al. (2014). Chacune des plages identifiées a été enregistrée indépendamment. Elles ont été localisées à la fois sur l'élément anatomique et à la fois sur la pièce au niveau de l'axe transverse et longitudinal. L'orientation des impressions a été notée conformément au positionnement de l'outil lors de son utilisation. Afin de mesurer l'intensité de la retouche, nous avons défini une échelle d'intensité allant de peu intense (i1) à très intense (i3) prenant en compte à la fois le nombre de marques et leur profondeur. Les traces ont été par la suite catégorisées selon différentes morphologies : hachures (rectilignes ou sinueuses et lisses ou rugueuses), *pits* (ovales ou triangulaires) et/ou une *scaled area*. Enfin, nous avons noté si les marques étaient isolées, dispersées ou concentrées sur la pièce. Dans la plupart des cas, les plages de retouchoir ont une

morphologie spécifique et peuvent être distinguées des marques de percussion. En effet, l'un des critères discriminants est le nombre de marques, qui est plus important lors de la retouche d'outil que lors de l'extraction de la moelle. Les retouchoirs sont généralement choisis parmi les fragments d'os longs obtenus après la fracturation en vue de récupérer la moelle. Ces fragments choisis peuvent être plus ou moins frais. Les restes choisis pour retoucher les outils lithiques ne semblent pas avoir été préformés dans le but d'être utilisés. On parle la plupart du temps d'outil peu élaboré pour mentionner les retouchoirs. Cependant, des études ont montré que la sélection des restes pouvait être le fruit d'une recherche en partie standardisée et sur le site de Scladina (Belgique) certains os d'ours des cavernes semblent ainsi avoir été sélectionnés à dessein par une partie d'une chaîne opératoire particulière (Mozota Holgueras 2009 ; Jéquier et al. 2012, Abrahams et al. 2014).



Figure 5: Retouchoir sur fragment diaphysaire indéterminé de MONG. Provenance : niveau 37 de Riparo Tagliente ; conservation : Université de Ferrara (Italie) ; échelle = 1cm ; cliché D. Vettese).

II. 2. 3. *Réflexions sur la terminologie des marques de percussion*

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Towards an understanding of hominin marrow extraction strategies:

a proposal for a percussion mark terminology

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Percussion marks have been studied in the field of archaeology for more than a century. Researchers have identified, characterized and analysed them in order to distinguish them from traces of environment modification to bone and reconstruct hominin subsistence strategies. The multiplicity of studies based on percussion marks in different languages has led to a proliferation of different terminologies used for the same marks, especially in English. In addition, as a result of numerous experimental studies or ethnological observations, it is possible to accurately identify the different steps of the butchery process and each of the related marks. We know from experimental studies that the morphology of percussion traces inflicted by the same tools can differ as their morphology depends on many factors (i.e., location and intensity of blows, intrinsic bone variables). In addition to this, carnivore and hominin traces can be superimposed, which sometimes renders their interpretation difficult. Renewed interest in these percussion marks owing to the emergence of new technical means highlighted the need to review their classification and clarify the nomenclature. With this in mind, we reviewed the abundant scientific literature to propose a refined and descriptive nomenclature. The aim is to provide a coherent terminology for the description and analysis of impact fractures in different European languages. We also propose classifying percussion marks into three categories: 1) percussion marks sensu stricto; 2) traces consecutive to bone breakage and 3) striation marks related to marrow extraction.

Key-words: Percussion marks; Terminology; Zooarchaeology; Taphonomy; Long bone breakage.

*Approche techno-culturelle de la fracturation des os longs chez les Néandertaliens (Sud-Ouest de l'Europe, MIS 5-3) :
une systématisation des gestes ?*

II. 2. 3. 1. Résumé de l'article en français.

Depuis plus d'un siècle, les archéologues n'ont cessé de s'intéresser aux marques de percussion. Les chercheurs se sont attachés à les identifier, à les caractériser et à les analyser dans l'optique de les distinguer des marques laissés par les carnivores et des différentes modifications dues à la diagénèse. Cette tâche, fastidieuse, s'inscrit dans l'optique d'apporter des indices concrets pour reconstruire les stratégies de subsistance des hominines anciens. De nombreuses études à la fois expérimentales et ethnologiques se sont attelées à identifier les différentes étapes du processus de traitement boucher des carcasses animales. Grâce à ces travaux, chacune des marques laissées au cours de ce processus ont pu être associées aux étapes précédemment identifiées. Une des étapes clés de ce processus, la récupération de la moelle jaune des os longs, semble avoir été une pratique quasi-systématique durant le Paléolithique, i.e. chez Néandertal. Cette ressource alimentaire est de première nécessité pour les hominines. Cela répond à un besoin plus important en graisse, en particulier dans un environnement aride et froid. Différentes marques peuvent se former lors de l'ouverture de la cavité médullaire au cours de l'extraction de cette moelle jaune. Les diverses études taphonomiques, qui se sont intéressées aux marques de percussion, ont permis de démontrer l'équifinalité de certaines de ces traces. Certains travaux expérimentaux ont aussi permis de montrer qu'un même outil peut causer des traces morphologiquement différentes. De plus, le type de marque de percussion dépend de nombreux facteurs, tels que la localisation, le type d'outils, l'intensité des coups ou encore la structure des os eux-mêmes. Enfin, les traces laissées par les hommes et les carnivores sont parfois difficiles à distinguer les unes des autres. Dans certains cas, délicat d'interpréter ces marques en contexte archéologique. L'émergence de nouvelles techniques d'analyse de ces stigmates issues de la percussion confirme un regain d'intérêt pour ces traces anthropiques, et met en lumière la nécessité de clarifier leur nomenclature et de revoir leur classification.

Jusqu'à présent, il n'existe pas de consensus terminologique clair pour les marques de percussion contrairement aux marques de découpe par exemple. La longue histoire de l'étude de ces marques peut expliquer en partie l'absence d'une nomenclature homogène. Les besoins d'une terminologie claire et bien définie se sont pourtant récemment imposés. D'une part, une telle terminologie constituerait une base solide, sur laquelle s'appuyer, pour comparer les différentes études qui s'intéressent aux traces de percussion. D'autre part, cela s'impose comme un prérequis à une meilleure compréhension des pratiques bouchères dans leur ensemble. C'est pourquoi nous avons revu ici l'abondante littérature scientifique existante afin de proposer une refonte de la nomenclature. Notre travail s'appuie sur une terminologie descriptive qui semble la plus à même de décrire et d'analyser les marques liées à l'extraction de la moelle. Ce travail collaboratif

propose par ailleurs de réunir chacun des termes définis dans différentes langues européennes : l'anglais, le français, l'espagnol, l'italien et l'allemand. La classification que nous proposons regroupe ces marques en trois catégories : les marques de percussion *sensu stricto*, les traces annexes qui apparaissent lors de l'ouverture de la cavité médullaire et les marques de percussion indirecte. Ces deux dernières catégories peuvent être regroupées en tant que marques auxiliaires à la percussion, non spécifiques à la percussion directe.

Pour bien comprendre l'arborescence et la multiplicité des termes utilisés pour caractériser et définir les marques de percussion, il est indispensable de recontextualiser la recherche de ces marques anthropiques et d'en faire l'épistémologie. Ainsi, dans l'article, après une brève introduction, nous présentons un historique non exhaustif des travaux majeurs qui se sont intéressés aux marques de percussion, accompagné de perspectives méthodologiques. Par la suite, pour comprendre à la fois la formation des fractures et des marques de percussion, nous décrivons la structure des os longs et les différents facteurs entrant en jeu lors de la fracturation. Une description des différentes techniques existantes pour ouvrir la cavité médullaire est ensuite effectuée, comprenant : la technique de *batting*, la technique du marteau sur enclume et enfin la technique mixte. Dans la dernière partie de ce travail, nous proposons une terminologie descriptive cohérente. Au vue de l'importance de cette dernière partie, j'ai tenu à proposer également une traduction des définitions en français dans le cadre de ce mémoire de thèse.

II. 2. 3. 2. *Lexique en français.*

II. 2. 3. 2. 1. Les marques de percussion *sensu stricto*

Les éclats adhérents : Un éclat adhérent est un éclat dont la ligne de fracture est incomplète. Il reste donc toujours attaché à l'os. L'éclat est de forme semi-circulaire, visible sur la surface corticale. L'arc de cercle commence aux deux points d'inflexion dont chacun coupe le bord de fracture. Dans certains cas, les éclats adhérents possèdent un feuilletage ou un enlèvement conchoïdal médullaire ou interne. S'il se détache, il forme à la fois une encoche et un éclat indépendant. Un ou plusieurs éclats adhérents peuvent être associés à une marque d'écrasement ou une encoche.

Les marques d'écrasement : La marque d'écrasement est, comme son nom l'indique, une lésion de la corticale recouvrant la spongiosa et qui s'enfonce dans cette dernière. Elle est le plus souvent située à proximité des portions articulaires. La structure alvéolaire de l'os spongieux absorbe le choc de l'impact différemment du cortex de la diaphyse. La trace est de forme ronde ou ovale, et le plus souvent rassemble de multiples éclats adhérents autour d'un point central. Cette marque peut être à l'origine d'une ou plusieurs lignes de fracture. Les marques d'écrasement peuvent aussi être créées par la répétition de nombreux coups aux mêmes endroits.

L'éclat de percussion : Les éclats osseux de percussion partagent les mêmes caractéristiques que les éclats lithiques produits lors du débitage. De nombreux auteurs soulignent que les éclats osseux peuvent présenter les caractéristiques suivantes :

- une plateforme à l'emplacement de l'impact de percussion ;
- un bulbe de percussion près de la plateforme ;
- des marques d'ondes ayant pour origine le bulbe ou présents à proximité ;
- une largeur plus grande que la longueur ;
- une surface corticale réduite ou absente.

L'encoche de percussion : les encoches de percussion se situent au niveau du bord de fracture qui est coupé par deux points d'inflexion (Figure 6). Depuis ces points, une encoche semi-circulaire apparaît avec un enlèvement interne conchoïdal et parfois un enlèvement cortical conchoïdal.

Selon des catégories proposées par Capaldo et Blumenschine (1994) et modifiées par Galan et al. (2009) nous proposons :

- l'encoche complète ou classique : une encoche avec deux points d'inflexion visibles au niveau de la surface corticale et médullaire, possédant un feuilletage unique (ou enlèvement interne conchoïdal) qui n'est pas coupé par une autre encoche ou son feuilletage.
- les encoches complètes opposées : deux encoches isolées situées sur une même diaphyse sur des bords de fracture opposés ;
- l'encoche incomplète : une encoche qui ne possède qu'un seul point d'inflexion. Le second est manquant car une ligne de fracture sépare l'encoche en deux parties ou parce qu'une seconde encoche coupe la première ;
- la double encoche : deux encoches qui partagent un même point d'inflexion. Elles sont situées sur le même bord de fracture. L'un des deux feuilletages vient couper l'autre, montrant une antériorité de la première encoche. Dans certains cas, plusieurs encoches peuvent s'aligner les unes à la suite des autres sur un même bord de fracture ;
- l'encoche inversée ou bifaciale : une encoche possédant à la fois un enlèvement conchoïdal interne et un enlèvement cortical ;
- une micro-encoche : une encoche de petite taille mesurant moins d'un centimètre.

Cette micro-encoche peut apparaître au sein d'une encoche de percussion classique. Dans ce cas, elle localise précisément l'emplacement du point d'impact. Ainsi, un *groove* ou un *pit* triangulaire peut apparaître dans une encoche si la surface dure en contact avec l'os est pointue ou anguleuse.

- l'encoche avec une micro-encoche interne sur le bord de l'encoche (entre les deux points d'inflexion).
- l'encoche avec un *pit* triangulaire ou un *groove* sur le bord de l'encoche (entre les deux points d'inflexion).

Les *pit* et *grooves* de percussion : les *pits* de percussion sont des cupules superficielles présentes sur la surface corticale (Figure 7). Ils sont de formes ronde ou triangulaire. Ils sont le plus souvent accompagnés de micro-striations ou de stries. Ces marques sont produites par le rebond du matériau qui frappe l'os sans créer de fissures ou de fractures. Nous distinguons deux types de *pits*, d'après les catégories proposées par Mallye et al. (2017) :

- *pit* ovoïde : elle est causée par une surface ronde lors de l'impact.

- *pit* triangulaire ou linéaire : elle est causée par une surface tranchante ou pointue lors de l'impact.

Les *grooves* de percussion sont des sillons superficiels qui apparaissent sur la surface corticale. Leur forme peut être soit ovale allongée ou linéaire. Le *groove* possède une forme en V en vue transversale. Il est au moins deux fois plus long que large contrairement au *pit*.



Figure 6: Double encoche sur un fragment diaphysaire de radius de cerf. Provenance : niveau g de la grotte de Saint Marcel ; conservation : Cité de la Préhistoire, Orgnac, Ardèche (France) ; (échelle = 1cm ; cliché D. Vettese).



Figure 7: Dépression et sillon de percussion, enlèvement cortical sur un fragment diaphysaire de radius de cerf. Provenance : niveau g de la grotte de Saint Marcel ; conservation : Cité de la Préhistoire, Orgnac, Ardèche (France) ; (échelle = 1cm ; cliché D. Vettese).

II. 2. 3. 2. 2. Les marques consécutives à la fracture

Les fractures et les fissures :

Une ligne de fracture est une brèche dans l'épaisseur corticale de l'os. Le bord de fracture est situé de chaque côté de la ligne de fracture.

La texture et la forme du bord de fracture peuvent indiquer à quel moment entre la mort de l'animal, son enfouissement et sa découverte lors de la fouille, la fracture s'est produite, i.e. ante-mortem, peri-mortem ou post-mortem. Au regard de leur courbe, certaines fractures fraîches peuvent imiter des marques associées à la percussion. De par leur forme elles peuvent ressembler à une encoche ou à un enlèvement cortical conchoïdal.

Les fissures courent le long de l'épaisseur corticale d'un fragment sans s'achever par une fracture.

Les traces d'ondes : Les marques de peignage ou de glacis sont situées au niveau ou à proximité du bulbe ou de la plateforme. Dauvois (1974) considérait ces marques comme des ondes de choc lors du coup. Pour Johnson (1985) elles constituent des indices des techniques de percussion. Elles se forment sur les bords de fracture de l'os compact et pas seulement sur les éclats de percussion. Ces traces sont associées aux fractures sur os frais.

Le peeling : Le *peeling* est une marque caractérisée par une surface rugueuse avec des sillons parallèles ou une texture fibreuse causée par la séparation de deux parties d'un os frais lorsque la fracture est incomplète et toujours attachée. White définit ces traces pour la première fois en 1992. Par la suite, Pickering et ses collègues (2013) ont défini de façon expérimentale sur les côtes trois types de *peeling* cortical en fonction de leur extension sur la surface des os : l'arrachement classique, l'arrachement général et l'arrachement incomplet.

Les pseudo-encoches : Une pseudo-encoche possède une forme similaire à une encoche mais dépourvu de toutes les caractéristiques. Peuvent être manquant un des deux points d'inflexions ou le feuilletage. Sa forme peut être plus anguleuse et non semi-circulaire. Elles ne résultent pas de l'impact lors de l'extraction de la moelle mais peuvent être produites par une fracture.

Selon la division établie par Capaldo et Blumenschine (1994) :

- l'enlèvement cortical conchoïdal : un enlèvement de forme conchoïdal sur la surface corticale. La forme semi-circulaire se détache depuis le bord de fracture. Mais l'enlèvement ne s'enfonce pas dans l'épaisseur de la corticale ;

- l'enlèvement interne conchoïdal : il possède les mêmes caractéristiques que l'enlèvement cortical conchoïdal mais se forme à la surface de la cavité médullaire ;
- les micro-encoches groupées : de nombreuses micro-encoches alignées le long du bord de fracture.

II. 2. 3. 2. 3. Les stries liées aux marques de percussion

Les marques de raclage : Les traces de raclage se forment lorsque le tranchant de l'outil lithique est utilisé perpendiculairement à l'os pour retirer les tissus tels que les muscles, les tendons ou le périoste. Les observations ethnologiques ont mis en évidence que les Nunamiut, par exemple, retiraient le périoste des ossements avant de les fracturer. Ces traces sont longues, fines, superficielles et parallèles. Néanmoins, quelques expérimentations ont montré qu'il était possible de fracturer des os sans ôter le périoste (Galán et al. 2009; Vettese 2014).

Les microstriations et striations : Ces marques ont pour origine les aspérités de l'enclume ou du percuteur. Au moment de l'impact, elles se forment au niveau de la surface corticale de l'os lorsque l'os entre en contact (ripage) avec le percuteur ou l'enclume. Elles sont superficielles, courtes et parallèles. Elles sont parfois associées avec un *pit* ou une encoche de percussion.

*Approche techno-culturelle de la fracturation des os longs chez les Néandertaliens (Sud-Ouest de l'Europe, MIS 5-3) :
une systématisation des gestes ?*

II. 2. 3. 3. *Publication n°1:***Towards an understanding of hominin marrow extraction strategies: a proposal for a percussion mark terminology**

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Abstract:

Percussion marks have been studied in the field of archaeology for more than a century. Researchers have identified, characterized and analysed them in order to distinguish them from traces of environment modification to bone and reconstruct hominin subsistence strategies. The multiplicity of studies based on percussion marks in different languages has led to a proliferation of different terminologies used for the same marks, especially in English. In addition, as a result of numerous experimental studies or ethnological observations, it is possible to accurately identify the different steps of the butchery process and each of the related marks. We know from experimental studies that the morphology of percussion traces inflicted by the same tools can differ as their morphology depends on many factors (i.e., location and intensity of blows, intrinsic bone variables). In addition to this, carnivore and hominin traces can be superimposed, which sometimes renders their interpretation difficult. Renewed interest in these percussion marks owing to the emergence of new technical means highlighted the need to review their classification and clarify the nomenclature. With this in mind, we reviewed the abundant scientific literature to propose a refined and descriptive nomenclature. The aim is to provide a coherent terminology for the description and analysis of impact fractures in different European languages. We also propose classifying percussion marks into three categories: 1) percussion marks *sensu stricto*; 2) traces consecutive to bone breakage and 3) striation marks related to marrow extraction.

Key-words: Percussion marks; Terminology; Zooarchaeology; Taphonomy; Long bone breakage.

Introduction

Animal exploitation strategies by hominins are still poorly understood. This is particularly true of the extraction of marrow from animal long bones. Yet, yellow marrow recovery may be quasi-systematic among Palaeolithic hunter-gatherers, e.g., Neanderthals, mainly due to their important dietary fat requirements, especially in dry and cold environments (Speth 1989; Speth et al. 2012). The reasons underpinning this poor comprehension include the absence of a well-defined terminology, especially when anthropogenic percussion marks are reported. A well-defined terminology is the basis for every comparative study and is an essential prerequisite for our understanding of butchering practices. A huge variety of characteristics is currently considered to represent evidence of bone breakage. In recent years, the increasing interest in subsistence strategies has highlighted the problem. The identification and analysis of percussion marks is crucial for understanding human interaction with animal carcasses in terms of anatomical know-how, exploitation techniques, and the gestures employed during marrow removal.

Percussion and cut marks on animal bones, especially mammals ones, are among the most commonly observed butchery traces and have been widely studied at Palaeolithic sites since the beginning of the twentieth century (Martin 1906; Breuil 1938). Throughout time, zooarchaeologists have used different terminologies to describe the same types of marks (i.e., percussion notch, impact cone, conchoidal flake scars, etc.). In addition, these terminologies have been created in different languages. The diverse and rich scientific literature focused on the percussion marks was written in various European languages. Taking this into account, it is necessary to confront all the synonymous terms used in those previous work also in different languages. In this context, it is imperative to use consistently the same terminology for comparative studies in order to share data across borders. Moreover, new methodologies (e.g., microscopic observations, geometric morphometric, 3D modelling or GIS analyses of distribution along the diaphysis...) have increased our knowledge and present new challenges for the study of these traces (Njau 2012; Blasco et al. 2013; García-Moreno et al. 2014; Arriaza et al. 2018; Maté-González et al. 2019; Stavrova et al. 2019).

We aim to overcome this shortfall by providing a coherent terminology for the description and analysis of impact fractures based on the collation of currently existing terms and definitions from different European languages (English, French, Spanish, Italian and German). We begin with a historical and methodological perspective to contextualize the problems exposed and assess the difficulties encountered by zooarchaeologists. For a better understanding of fracture dynamics,

the bone structure of long bones is described followed by an outline of the most important dynamic loading techniques. Finally, we propose a consistent terminology.

2. Long bone breakage: a historical and methodological perspective

2.1. Bone breakage patterns against the background of taphonomy

Following Weigelt (1927) with his "biostratinomy" defined as a paleontology discipline; Efremov (1940) used the term "taphonomy" and added a methodological framework to a poorly defined field of science. This new field of research provided indicators for distinguishing natural alterations from anthropogenic modifications, allowing for the identification of the impact of human activities on bone assemblages. Taphonomy used the model of analogical thinking based on actualism and defined as follows by Gifford-Gonzalez (2018 – p.62): "a methodologically uniformitarian approach offers the historical sciences a practical research strategy for learning more about the past using modern analogies". Through ethology (animal behavior studies), ethnology (human behavior studies) and archaeological experiments, archaeologists aim to make hypotheses about the various processes causing bone damage. They follow the "visual model for a nested set of causal relationships" defined by Gifford-Gonzalez (2018, – p. 62) to identify the origin of percussion marks. Using her terminology, the actor caused the traces via the effector. For example, a hominin (actor or agent) caused a percussion notch (trace) with a hammerstone (effector). Actualistic studies can provide information on the processes that caused the breakage and help to identify the actors who broke the bones (e.g., Martin 1910; Breuil 1938; Leroi-Gourhan 1952; Dart 1957; Poplin 1973; Blumenschine 1988; Oliver 1989; Anconetani 1999; Pickering and Egeland 2006; Galán et al. 2009; Blasco et al. 2013, 2014; Njau and Gilbert 2016; Moclán and Domínguez-Rodrigo 2018; Parkinson 2018).

2.2. Historic perspective and context of the recognition of the Paleolithic marrow recovery process

At the beginning of the twentieth century, researchers attempted to understand the reasons for the presence of numerous bone splinters among prehistoric bone assemblages (Martin 1910; Black et al. 1933; Breuil 1938; Pei 1938; Breuil and Boyle 1939). Some experimental studies focused on natural and anthropogenic bone breakage processes. In addition, comparisons between archaeological and paleontological sites also contributed to distinguishing hominin traces from those of other agents. As a result of these attempts, two explanations were advanced for systematic long bone breakage by humans: marrow extraction and bone tool making (Martin 1910; Breuil 1938; Pei 1939, 1938; Dart 1957, 1960; Poplin 1973, 1978; Dauvois 1974; Noe-

Nygaard 1977; Bonnichsen 1979; Morlan 1979, 1980). In the first half of the twentieth century, Breuil (1938) developed the theory of the “Bone and Antler Industry of Choukoutien”, and some years later, Dart (1957) defined the osteodontokeratic technology as a hominin “bone, tooth, and horn” culture (Breuil and Lantier 1959; Wolberg 1970).

2.3. Identifying the agents that cause green bone breakage

Through works focused on Lower and Middle Pleistocene archaeological sites in eastern Africa, Isaac categorized the sites based on the concentration of bones and lithic artefacts and faunal assemblage modifications (Isaac 1971, 1978, 1983). In addition, during the early eighties, ethological and ethnological observations provided reading keys for long bone breakage processes. Some authors began to record spiral fractures among extant carnivore accumulations (i.e., Washburn 1957; Miller 1975; Hill 1976; Bonnichsen 1979; Binford 1981; Brain 1981; Haynes 1982; Haynes and Stanford 1984; Gonzales 1991). After that, actualistic studies succeeded in showing that both carnivores and humans could accumulate broken bones in archaeological and paleontological contexts. Carnivores and hominins could consecutively occupy the same sites and accumulating accumulate bones at the same place bones. Moreover, carnivores could scavenge piece of carcasses abandoned by humans and inversely or they could transport bones from kills or consumption site to places occupied by humans occupations. That is means that both actors could intricate create mixed bone accumulations (e.g., Potts and Shipman 1981; Brain 1981; Blumenschine 1986; Bunn et al. 1986; Hill 1989; Cavallo and Blumenschine 1989; Blumenschine and Selvaggio 1991; Bunn 1991; Marean et al. 1992; Blumenschine and Marean 1993; Selvaggio 1994; Capaldo 1995, 1997; Blumenschine et al. 1996). Fossil fauna accumulations are often palimpsests and identifying the actors of bone fracturing can be difficult. In addition, the use of ethnographic studies provided new perspectives for past behaviors (Poplin 1973; Delpech and Rigaud 1974, 1977; Teleki 1975). Binford (1978, 1981) highlighted breakage patterns for marrow extraction among the Nunamiut in Alaska, depending on intra and intergroup factors. He mentioned that blows were not random but focused on the most fragile areas of the bone. Furthermore, Binford (1984) theorized scavenging behaviors through ethnographic observations. In addition, the environmental context may also play a preponderant role in bone fragmentation, as ambient temperatures and humidity level. Myers et al. (1980), and then Behrensmeier et al. (1989) also demonstrated that trampling by ungulates can cause breakage features. Dauvois (1974) even suggested that blocks from cave collapse could also cause bone damage similar to animal and hominin marrow recovery processes. Oliver (1989) and Griggo (2013) confirmed this

with examples from Shield Trap Cave (Montana, U.S.A., Holocene period) and Tempiette Cave (France, Holocene period).

After the above-mentioned works, many researchers defined criteria to differentiate sub-contemporaneous fractures (green bone fractures) from those due to post-depositional agents (dry bone fractures) (e.g., Haynes 1983; Morlan 1984; Johnson 1985). In 1991, Villa and Mahieu (1991) described the criteria in order to distinguish green bone from dry bone fractures: outline, edge texture and angle, and long bone shaft length and circumference. Thereafter, Outram (1999, 2001, 2002) combined these criteria proposing the Fracture Freshness Index (FFI) more efficient to categorize the breakage temporality. Hominins, carnivores or other environmental factors were able to create similar green bone spiral fractures. It then became necessary to establish clear features to differentiate the cause of breakage, with for example, the associated bone surface modifications (tooth marks, percussion marks, cut marks, etc.). Identifying and categorizing the various marks caused by percussion may help to understand the actors and processes. By contrast, our aim is not to designate the function that caused the breakage. Indeed, anthropogenic green bone fractures can be part of various “*chaînes opératoires*” including activities such as marrow recovery, or bone retouchers manufacturing for example..

Besides, ethnological observations have shown that current hunter-gatherers could extract marrow in a specific way, producing breakage patterns (Binford 1978; Enloe 1993; Abe 2005; Costamagno and David 2009). Indeed, some groups may systematically hit each bones element at a same location. Thus, the percussion marks distribution could design specific patterns to break bones. Therefore, zooarchaeological analyses tested the presence of butchering traditions for Middle and Upper Palaeolithic periods based on the distribution of percussion marks on long bones (Blasco et al. 2013; Masset et al. 2016; Vettese et al. 2017). Consequently, a common nomenclature and categorization of percussion damage now appears essential in order to compare the percussion marks distributions along the diaphysis for various Palaeolithic sites.

3. Why revise the terminology?

The current nomenclature used by the scientific community is varied and is frequently based on a wide diversity of terms and definitions. For example, the notch caused by hominin percussion is described by many names, such as impact mark, notch or fracture cone (Bonnichsen 1979; Archer et al. 1980; Binford 1981; Bunn 1982; Haynes and Stanford 1984). The term notch corresponds to a strict morphological description of the marks, regardless of the actors, i.e., humans or carnivores. Even if breakage mechanisms are different (static loading by carnivores

[pressure] and dynamic loading by hominins [percussion]), the marks can be similar in shape (Lyman 1987; Gonzales 1991; Gifford-Gonzalez 2018). Thus, for isolated notches, it can be difficult to distinguish between a tooth notch and a percussion notch, although some features may help with the distinction. For example, the ratio between the length and the width of the notches, especially on small and medium-sized ungulate long bones, can identify the agent. The presence of associated human or carnivore marks or the type of notch (isolated, double or opposite) can also be an identification feature (Capaldo and Blumenschine 1994; Voormolen 2008; Moclán and Domínguez-Rodrigo 2018).

The notch is not the only mark in question. Blumenschine and Selvaggio (1988) proposed identifying percussion activity based on the types of pits and grooves and the presence of related microstriations: "percussion marks". To describe these traces, they used the terminology of pits and grooves for the first time, similar to the terms used to describe carnivore tooth marks (e.g., (Maguire et al. 1980; Blumenschine 1995; Barba and Domínguez-Rodrigo 2005; Galán et al. 2009; Saladié et al. 2013). Indeed, except for microstriations, there are few morphological differences between tooth pits and percussion pits, even if the mechanisms are different (static or dynamic loading) (Blumenschine and Selvaggio 1988; Capaldo and Blumenschine 1994; Yravedra et al. 2018). In our opinion, using the term "percussion marks" is ambiguous. On one hand, it describes some particular traces present in the context of anthropogenic breakage, and on the other hand, it corresponds to a generic term, which is used to describe all the marks resulting from the impact between a hard material and the bone.

The multiplicity of terms in the currently used nomenclature and the use of descriptive or interpretative (agents) terminology can cause confusion and lead to interpretation problems. Indeed, current categories can induce misinterpretations or complexity in the identification process of the origin of marks. Many researchers have attempted to clarify the nomenclature and have suggested typologies (Patou-Mathis 1985; White 1992; Capaldo and Blumenschine 1994; Fisher 1995; Boulestin 1999; Costamagno 1999; Domínguez-Rodrigo 2002; Pickering and Egeland 2006; Domínguez-Rodrigo et al. 2009; Symes et al. 2014; Gifford-Gonzalez 2018). However, they have been faced with many challenges. For example, the chopping mark (Bonnichsen and Will 1980; Binford 1981; Shipman 1981; Bunn 1981; Johnson 1985; White 1992; Capaldo and Blumenschine 1994; Fisher 1995; Outram 2002; Pickering and Egeland 2006; Lyman 2008; Galán et al. 2009; Blasco et al. 2013; Gifford-Gonzalez 2018), despite its classification as a cut mark (cf. Lyman, 2008), could be the result of hammerstone percussion and batting (Blasco et al. 2014). It could be conceived as a hybrid mark between cutting and percussion (Gifford-Gonzalez 1989; Lyman 2008). Nevertheless, percussion action is sometimes used to cut tissues during the

disarticulation stage. These marks can thus result from both percussion and cut marks. Moreover, some traces categorized as percussion marks are not directly caused by impacts, for example, peeling or scraping marks. The former is the result of the pullout of the two parts of the bone still connected after the impact and the latter is due to the cleaning of bone surfaces before the blow. Finally, to identify butchery traditions, it is fundamental to differentiate the marks directly linked to the impact from auxiliary marks (scraping marks, microstriations, pseudo-notches, cracking, peeling, fracture lines, etc.). Moreover, recording the exact location of the percussion impact may enable the identification of a potential standardized and counterintuitive pattern expressing specific butchery practices and differentiate them from other agents (Blasco et al. 2013; Masset et al. 2016; Vettese et al. 2017; Parkinson 2018; Stavrova et al. 2019). Indeed, to compare butchering traditions between several sites, percussion traces should be recorded by a solid nomenclature and common definitions.

4. Long bone structure and response to dynamic percussion

Percussion mark identification is directly linked to an understanding of the raw material, in this case, bone. When the physical and chemical perimortem composition of a bone is known, it should be possible to estimate its response to the dynamic force applied during marrow recovery. These data are crucial for identifying the type of action, the tool used to break the bone and the techniques and gestures employed. Moreover, individuals who regularly break long bones acquire an empirical approach to bone and develop specific skills that enhance efficiency. Thus, their skills include habits and preferences gained by experience and/or group traditions. This know-how cannot be assessed without differentiating between physical bone features and socio-cultural practices.

In addition, some extrinsic factors due to the life of the animal could play a minor role in the formation of the fracture lines and marks produced by the percussion process, such as animal disease (e.g. osteoporosis) or bone injuries. Moreover, the shape of each long bone influences the technique employed and the blow location, as well as the position adopted for breakage and marrow extraction (Bonnichsen 1979). The tools and the techniques employed vary according to individuals or groups, but also according to the size and the cortical thickness of the bone.

4.1. The physical and chemical composition of bone

The composition of bone as a biological hard tissue is well known, notably in biomechanics (Currey 1984, 2012; Weiner and Wagner 1998; Ritchie et al. 2009; Wang and Gupta 2011).

Archaeologists focus on the specific mode of bone breakage (Johnson 1985; Balasse et al. 2015; Fernández-Jalvo and Andrews 2016; Brugal 2017). Bone is a composite material with seven levels of hierarchical structures. These hierarchical levels interact with each other and improve the mechanical strength and toughness of the bone (Currey 1984; Wang and Gupta 2011). Bone has a compact, heterogeneous, viscoelastic and anisotropic structure. An anisotropic material does not present a unique response to mechanical constraints. The trabecular (compact bone at the microstructural level) is a composite material: (1) the mineral phase accounts for 45% (hydroxyapatite), (2) the organic phase constitutes 35% of bone weight (collagen) and (3) the last part is composed mainly of water (Follet 2002; Gifford-Gonzalez 2018). Perimortem, both elastic and plastic deformations are responsible for the two phases (organic and mineral). Fresh bone with a high water content does not react in the same way as dry bone. The internal structure of a bone dictates the response to stress depending on the direction of the applied force.

4.2. Long bone specificity

The vertebrate skeleton is composed of different types of bones: short bones (carpal, tarsal...), flat bones (scapula, coxal...) and long bones (femurs, humerus...) (Barone 1976). These bones have different shapes, and varying proportions of spongiosa and compacta tissues. Moreover, bones contain different proportions of yellow marrow. Long bones have the highest yellow marrow content in relation to mandibles or phalanges (Jones and Metcalfe 1988; Madrigal and Holt 2002). Most herbivores have 12 long bones, consisting of pairs of radio-ulnas, humeri, metacarpals, femurs, tibias and metatarsals. Contrary to primates or carnivores, herbivore metapodials are long and also contain a high quantity of yellow marrow.

All these long bones have a similar shape: one diaphysis and two epiphyses. The diaphysis has a cylindrical shape and is full of yellow marrow (adipose tissue), surrounded by a solid matrix called compacta. In addition, this dense part of the bone is covered by the periosteum; a fibrous membrane that absorbs the impact of the blows (Blasco et al. 2014; Balasse et al. 2015). The endosteum is, for its part, a membrane coating the medullary cavity. The spongiosa is an alveolar structure composing the epiphyses and enclosing the red marrow. These latter have a more or less rounded shape. When the long bone is placed on a flat surface, it stands on the two epiphyses, and the diaphysis is elevated most of the time. The thick part is much denser than the spongy tissue. The specific morphology, structure and moisture of the bone present an extraordinary energy-absorbing capacity (Evans 1961; Johnson 1985). Due to the heterogeneity of the articular portions, they absorb the impact better. Applying a sudden force or an impact produces most of the fractures. Johnson (1985) claimed that, "the bone is stronger in compression and shear than

in tension and failure starts on the tension side". The fracture line could appear at the opposite side of the impact point. The direction of force application, in which stress impact bone, dictates the type of fractures or incipient cracks (Lynn and Fairgrieve 2009; Gifford-Gonzalez 2018). Each long bone presents its own characteristics, which respond differently during the breakage process. It is thus necessary to adapt the position of the bone. One of the main differences lies in shaft morphology. The humerus and the femur have a rounded section, while tibias have a more rectangular-shaped or even triangular section. Radio-ulnas, like metapodials, have a semi-lunar cross-section. The fusion between the radius and the ulna strongly constrains the shape of the bone. The proximal portion of the ulna is thin and does not ensure the stability of the bone when it lies on its posterior side. In addition, spongiosa is not homogeneously distributed for all long bones, although it is mainly restricted to the articular part. For example, the distal part of the humerus has an internal structure with partitions inside the medullary cavity. Moreover, the metapodial shaft is denser than that of other long bones (Lam et al. 1999).

4.3. Inter-species and intra-species differences

Handling and breakage are not as easy according to the different sized-class of ungulates like an elephant, a megaceros or a chamois limb element. In addition, these actions depend on long bone size, density, cortical thickness or weight. Indeed, although herbivores have the same types of long bones, interspecies differences exist. First, long bone measurements and weight depend on herbivore size. For example, a bison femur is bigger and heavier than a roe deer femur. Likewise, cortical thickness and bone density vary with the size of the animal and according to the species (Metcalf and Jones 1988; Kreutzer 1992; Lyman 1992, 1994; Elkin 1995; Mullender et al. 1996; Lam et al. 1999). Depending on the species, the difference in thickness can double or even be multiplied by five (Barba and Domínguez-Rodrigo 2005). Proboscidean long bones are among the largest and have a proportionally reduced medullary cavity in comparison to other herbivores (Shoshani et al. 1985; Boschian and Saccà 2015; Boschian et al. 2019).

Finally, it is also necessary to consider the extrinsic factors related to the individual. Differences linked to the sex, age or ontology of an animal can occur within the same species. Robustness and medullary cavity size or even the quantity of spongiosa may vary. Moreover, long bone elements can be altered and weakened by different pathologies, such as bone diseases or macro or micro bone fractures. These can play a minor role in the formation of fracture lines during the percussion process.

5. Dynamic loading and percussion techniques

5.1. Techniques used to break bones

It is possible to discriminate percussion traces from other types of marks and understand the circumstances of their production by exploring the different techniques used to open the medullary cavity. This also highlights the abilities of hominins to recover marrow and the various techniques used to break long bones. To fully understand marrow extraction techniques, it is important to note that this individual activity is mainly used for small-, medium- or large-sized ungulates, but not for very large-sized animals. For example, it appears that several individuals are needed to break elephant long bones in order to recover the yellow marrow (Holen et al. 2017). It is thus possible to identify the gestures used during marrow recovery processes based on fossil percussion marks thanks to the different techniques and tools documented by ethnographic observations and archaeological experiments.

Following the observations of Oliver (1993) made among the Hazda in Tanzania and subsequent works, we differentiate four techniques for marrow exploitation:

- **static loading**; groups the pressure techniques, between an anvil and a stone or wooden tool, or tooth (gnawing a bone). Static loading is characteristic of carnivores and primates. They press bones between their jaws to recover yellow marrow and usually chew the spongy parts. Chimpanzees also use their teeth to break the long bones of other monkeys (*Colobus* sp.) or various small animals. They use a previously fashioned wooden stick to extract marrow after removing the articular head with their teeth ((Boesch and Boesch 1989). Prey caught by humans can be much larger and great strength is usually required to break long bones. The human jaw is weaker than that of large carnivores, such as hyenas and wolves, for example. Hominins did not have the necessary force to break large ungulate long bone shafts and epiphyses with their teeth. Thus, these types of anthropogenic traces are rare and, in any case, may be distinguished from those of carnivores, by their size and shape (Saladié et al. 2013). Archaeological data show that hominins applied static loading using pressure tools. Traces are consequently different from carnivore tooth marks, with some associated micro-striations.

- **torsional loading**; by wrenching or twisting a bone and flexing a bone by hand. Faunal remains from some archaeological sites provide evidence of bone breakage by hand or mouth by twisting, most often on flat bones. The mouth, in this case, is used like a third hand to facilitate breakage. For example, a rib fragment from Atapuerca (TD6) shows human tooth marks and peeling (Saladié et al. 2011; Fernández-Jalvo and Andrews 2016). Based on an experimental work, Pickering et al. (2013) defined three types of peeling damage according to their cortical expansion

on ungulate ribs. Ethnological observations on the Koi people by Brain (1969) indicated rib breakage by hand, creating some peeling marks. Nevertheless, we have to take special care when identifying peeling on fossil bones, since this damage can also be generated by carnivores (and not only by humans). Recent neotaphonomic observations have documented this modification among faunal remains consumed by brown bears and, to a lesser extent, by red foxes (Arilla et al. 2014, 2019). However, the use of twisting or flexing techniques to break long bones of middle or large-sized ungulates is uncommon and required great strength. These last techniques could leave some surface traces, and fracture lines and peeling traces, depending on bone type (White 1992; Martínez 2009; Saladié et al. 2013). Moreover, torsional loading could be used in addition to dynamic loading, after the first cracking or fracture.

- **friction loading**; when a bone is sliced or sawed. This technique is specific to humans.

- **dynamic loading**; summarizing techniques using percussion: bone clubs on an anvil, use of a hard object (a hammerstone, a panga machete, an axe or a knife) to strike a bone directly or indirectly with an intermediary object. Dynamic loading serves as an umbrella for all the percussion techniques and is mostly specific to humans extracting marrow (like sawing). The morphology of the human hand with the opposable thumb allows for the handling and grasping of bones and hammerstones (Young 2003). Some animals may have used dynamic loading, such as extant bears, which have been observed throwing cow femurs against a wall to break them and recover the marrow (personal observation) and bearded vultures which drop long bones on the rocks from a high altitude (Marín-Arroyo and Margalida 2012). In ethnological contexts, most of the percussion techniques observed involve iron tools. During the Pleistocene and early Holocene, humans used stones for percussion, i.e., chopper and chopping tools with sharp edges or pebbles. The Nunamiut also used unretouched pebbles as hammerstones (Binford 1981). In this paper, we focus on two dynamic loading techniques where bones play an active and passive role: (1) the bone-batting technique and (2) the hammerstone on anvil technique.

5.2. The batting technique

5.2.1. Background

Humans can use long bones as tools. In this case, the bone plays an active role during the percussion process, and directly strikes the surface. Before the 21st century, different terminologies were used to describe this type of active percussion, such as clubbing, beating or batting (Noe-Nygaard 1977; Blasco et al. 2014). The first author to mention this is Noe-Nygaard (1977). During her experiments, she broke the hind limb of a roe deer” by holding the bone by one end and beating it against a hard object of wood or stone using it as a club”. In 1980, Archer

and his colleagues set up an experiment with kangaroo long bones to better identify breakage patterns. They held fresh femurs in one hand and hit the diaphysis on the edge of hard stone. Oliver (1993) also described this technique of clubbing long bones on an anvil in the course of his ethnological observations on the Hazda. Lastly, a systematic experimental approach to bone fracturing, adopting this technique, was held by Anconetani (Peretto et al. 1996).

5.2.2. Description

This type of percussion is the simplest technique for breaking bones since it does not involve any tools. The individual takes a bone by one of its epiphyses or by the shaft and hits or clubs it on a hard surface (plane, rounded or with a sharp edge). This surface can be a large stone, a wall or the ground, a piece of wood or even a bone. Depending on whether the individual holds the bone by the epiphyses or diaphysis, it can hit either: the opposite epiphysis, the diaphysis far from the epiphysis to remove the opposite epiphysis or the middle part of the diaphysis to break the diaphysis in half. Due to long bone morphology, the diaphysis can only be struck against a prominent surface. Alternatively, the individual can hold the bone with one hand on each epiphysis. In this case, only the diaphysis can be stuck against a sharp or rounded edge.

5.3. The hammerstone on anvil technique

5.3.1. Background

The “hammerstone on anvil” technique is the most studied technique in experimental archaeology. The bone plays a passive role using percussion by a hammerstone on anvil. At the beginning of the 20th century, a paper mentioned this kind of experiment to recover marrow (Martin 1910). The author described how he broke equid long bones with rounded pebbles on a rectangular anvil with the help of two colleagues. Several similar studies have been reported, describing how Pleistocene hominins might have extracted marrow. Most of the studies are based on experiments combined with ethnological observations (i.e., Binford 1981; Turner 1983; Blumenschine and Selvaggio 1988; Capaldo and Blumenschine 1994; Lyman 1994; Fisher 1995; Peretto et al. 1996; Karr et al. 2005; Pickering and Egeland 2006; Domínguez-Rodrigo et al. 2009; Karr and Outram 2012, 2015; Yravedra et al. 2017).

5.3.2. Description

The name of this technique explicitly indicates the tools used to open the medullary cavity: a hammerstone and an anvil. The anvil is a passive instrument for placing the bone where a second instrument (hammerstone) hits it (Mourre 2004). The anvil is made of relatively hard material (the ground, stone, wood or bone). Its size and morphology (flat, rounded or sharp) vary according to

the technique employed and animal size. The hammerstone is a stone used to break the bone and could be a pebble, manufactured or not, with a sharp or rounded surface or edge, a piece of wood or another bone.

In the case of the use of an anvil larger than the length of the bone, the complete long bone is placed on the anvil, with the epiphyses lying on their surfaces, while the diaphysis is not in contact with the anvil. Alternatively, the diaphysis or one of the two epiphyses are placed on the anvil with the opposite epiphysis touching the ground. It is also possible to place the bone vertically with one of the epiphyses on the anvil and to hit the opposite epiphysis with a hammerstone.

5.4. *The mixed technique: a hybrid “chaîne opératoire”*

Marrow extraction from a long bone can require repeated hitting and breaking. Initial percussion often results in a broken bone with a large part of the shaft attached to an epiphysis and some splinters of varied sizes and sometimes a shaft cylinder. The broken bone has both sharp and smooth parts. Its size is reduced compared to the complete bone. The batting technique might initiate the fracture and the hammerstone on an anvil can help to continue fracturing. Experiments show that the opposite is also possible, i.e., fracturing the bone with a hammerstone on an anvil and once the first fissures appear, finishing breaking by hitting the bone against the sharp edge of an anvil, holding the bone by both epiphyses. The use of two percussion strategies on the same bone has been described as “mixed” percussion (Peretto et al. 1996). Depending on skills, habits or traditions, hominins could use one or several techniques. Current studies indicate the importance of the anatomical position of percussion traces to identify techniques and butchering traditions in archaeological contexts (Blasco et al. 2013; Masset et al. 2016; Vettese et al. 2017; Moclán and Domínguez-Rodrigo 2018).

6. Terminology and classification of percussion marks

6.1. Process and production of percussion marks

The morphology of percussion marks and their anatomical location differ according to the breakage techniques and tools used. The distribution and location of the marks vary depending on whether the bone is broken by batting or by a hammerstone (Blasco et al. 2013, 2014; Moclán and Domínguez-Rodrigo 2018). The results of a blow depend on the bone structure, i.e., whether compacta or spongiosa is involved and if the bone retained its periosteum. In addition, the strength and the abilities of the knapper, as well as the type of hammerstone (shape, size and

weight), also affect the type of percussion marks. Hitting a bone can have several consequences (adapted from Boulestin 1999):

- The periosteum absorbs the impact and protects the bone surfaces; the bone remains unaffected.
- The bone surface is modified, with or without cracking (pits, grooves);
- The bone surface is both modified and deformed, the cortical part is pushed into the bone cavity, with or without cracking or breakage (crushing);
- The bone is deformed by flake detachment, the mark left is the negative of this (notch);
- The bone is broken showing several fracture lines, without percussion marks.

The appearance of fracture lines is not related to percussion marks. Nevertheless, the percussion mark types are influenced by the appearance of the fracture lines. The impact produces a conchoidal cone of percussion which could create a notch on the shaft bone because as fractures radiate off or a crushing mark on the articular portion when the radiating fractures are stopped (dispersed) by the trabecular bone. The periosteum absorbs the impact and the fracture lines can appear on the opposite side of the blow. The long bone is weaker in tension than in compression (Johnson 1985).

Analyses focusing on percussion marks have highlighted two major problems of very different kinds: a double equifinality during percussion mark formation and the abundant terminology used to characterize them, which is currently not standardized (Lyman 2004).

Firstly, a double equifinality, some researchers have observed, through experimental studies, that the same tools leave different percussion traces and two different tools could leave same percussion marks (Blasco et al. 2013; Blasco et al. 2014; Vettese 2014; Chevillard 2018). The type of mark depends on many factors: location and intensity of the blow, or if the surface is hit many times in the same place with or without removal of the periosteum and the extrinsic factors related to the animal. The shape of percussion marks corresponds to the shape of the striking tool. Batting a long bone against a sharp edge or batting the bone with a retouched pebble may produce similar traces. If the instrument is round and smooth, marks are rounded or semi-circular, whereas, if the edge of the instrument is sharp, the scar is also sharp. One of the differences for the hammerstone on anvil technique is the possible presence of counterblow marks. These marks appear on the opposite side of the hitting surface as a result of the rebound effect on the anvil (e.g., Johnson 1985; Capaldo and Blumenschine 1994; Outram 1999; Galán et al. 2009; Gifford-

Gonzalez 2018). These marks are pits, microstriations, notches or pseudo notches. Due to the multiplicity of traces, it is sometimes difficult to discriminate blow marks from counterblow marks.

Secondly, as we exposed previously the current terminology is variable according to the authors and thus could be ambiguous. In this study, we aim to provide a common vocabulary, based on descriptive nomenclature.

We propose a standardized classification and nomenclature, which should enable researchers to differentiate direct traces caused by percussion, from indirect marks due to the anvil or percussor rebound effect or from marks consecutive to the breakage (peeling, scraping, etc.). We list below all types of percussion traces divided into three categories. The first category represents marks directly due to the impact. They are percussion marks *sensu stricto*. The second category groups the traces consecutive to the opening of the medullary cavity. The third group summarizes auxiliary striations related to marrow extraction. They are common to all the bone breakage techniques. Using these categories, we define a descriptive name for each type of mark. This usually corresponds to the most widely employed name in the current literature. We then propose a compilation of all the terms used in different languages (English, French, Spanish, Italian and German) in order to standardize and connect each type of mark with the appropriate terms in different languages. Each mark is illustrated with pictures from our own experiment performed in order to extract marrow (Vettese 2014; Stavrova et al. 2019). The experimenters used both a non-retouched hammerstone and a sharp-edged anvil.

6.2 Terminology and classification proposal

6.2.1 Percussion marks *sensu stricto*

Adhering flake

English: Adhering flake; chips; incipient notch; wide impact scars.

French: Eclat adhérent; point de frappe avec esquillement prolongé.

Italian: Bordo d'impatto con sfogliature; schegge secondarie; schegge incipienti; schegge parassite (meno usato).

Spanish: Esquirla parásita; lasca parásita.

German: anhaftender Knochen-Abschlag.

Definition: An adhering flake is a flake whose fracture line is incomplete and, thus, still attached to the bone (Figure 1 A, A' and B). The flake has a semi-circular shape visible on the cortical surface caused by two inflection points that cut a fracture edge. Sometimes, adhering flakes can show an

inner conchoidal or semi-circular scar. If it were detached, it would form a notch on one hand and a flake on the other. The adhering flake can be related to crushing marks.

References: (Martin 1910; Binford 1981; Villa et al. 1986; White 1992; Capaldo and Blumenschine 1994; Fisher 1995; Boulestin 1999; Díez et al. 1999; Rovira Formento 2010; Rovira Formento and Caceres 2013; Masset et al. 2016; Vettese et al. 2017).

Crushing mark

English: Crushed area; crushing; depressed margin; splintered.

French: Ecrasement; enfoncement.

Italian: Sfondamento incompleto; incrinamento dell'impatto; collassamento dell'area d'impatto.

Spanish: Aplastamiento; machacamiento.

German: Eindrückungen.

Definition A crushing mark is a lesion in the thin cortical bone covering the spongiosa, often located near articular portions (Figure 1 C and C'). This alveolar structure absorbs the shock of the impact differently than the more robust cortex of the shaft. The roundish lesion is formed by multiple dented in adhering flakes and is sometimes located at the origin of one or more fracture lines. Crushing marks can form by repeated blows to the same location, which lacked the force to create fracture lines. In this case, these marks could also appear on the diaphysis of long bones.

References: (Binford 1981; White 1992; Fisher 1995; Peretto et al. 1996; Boulestin 1998; Costamagno 1999; Thiébaud et al. 2009; Masset et al. 2016; Gifford-Gonzalez 2018) Vettese 2014; Chevillard 2018.

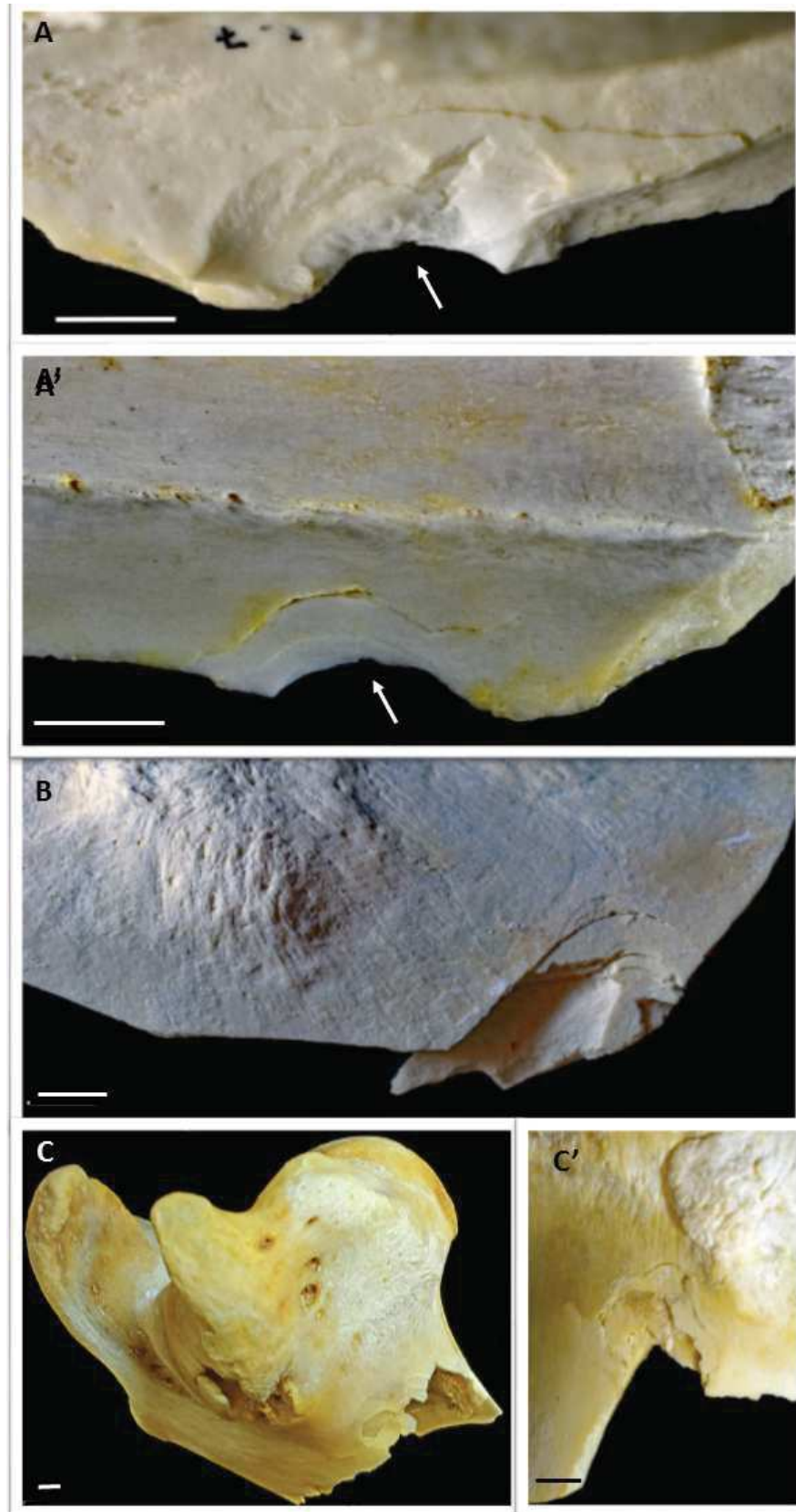


Figure 1: Direct percussion marks: some examples of crushing mark and adhering flakes on experimental bones (two adult *Bos taurus* species humerus). (A-A') Percussion notch with adhering flakes and inner conchoidal scar and micro-notch (white arrows) (medullary (A) and cortical (A') views); (B) Adhering flake still attached; (C-C') Crushing mark on a proximal epiphysis with some adhering flakes. Bare scales represent 1 cm.

Flake

English: Bone flake; flake; impact flake; positive flake; positive percussion flake; small percussion flakes.

French: Eclat; positif d'éclat.

Italian: Scheggia; scheggia d'osso; scheggia da impatto; scheggia corticale; scheggia midollare.

Spanish: Cono de percusión; lasca medular/cortical.

German: Knochen-Abschlag.

Definition: The percussion bone flake shares the same characteristics as lithic flakes produced by stone tool manufacturing (Figure 2 B). As mentioned by numerous authors, bone flakes may display:

- A platform at the impact point,
- A percussion bulb below the platform,
- Some ripple or hackle marks originating at or near the bulb,
- Greater breadth than length,
- Absence or reduction of the cortical surface.

References: (Brain 1981; Johnson 1985; Blumenschine and Selvaggio 1988; O'Connell and Marshall 1989; Fisher 1995; Costamagno 1999; Pickering and Egeland 2006; Rovira Formento 2010; Blasco et al. 2013; Vettese et al. 2017; Gifford-Gonzalez 2018)

Percussion notch

English: Chopper mark; chopping mark; chopping scar; Clactonian notch; complete or classic notch; conchoidal flake scar; conchoidal scar; dynamic impact scar; hammerstone impact notch; impact notch; impact scar; internal flake scars; loading point; normal notch; notch; outer conchoidal scar; percussion impact notch; percussion notch.

French: Coche; encoche; point d'impact; trace de percussion; zone de point d'impact.

Italian: Incavo; incavo di percussione; impatto; punto d'impatto; area d'impatto; sfondamento completo; scheggia concooidale; distacco; distacco in faccia midollare; distacco in faccia corticale; distacco corticale; distacco midollare; cono di percussione.

Spanish: Muesca de percusión; impacto de percusión; punto de impacto.

German: Schlagspur; Schlagmarke.

Definition: The percussion notch is located on a fracture edge (Figure 2 B). Two inflection points cut this edge. From these points, a semi-accurate notch appears with an internal conchoidal scar and sometimes an outer conchoidal scar. The percussion notch is the negative flake scar (Figure 2 B).

We follow the division established by Capaldo and Blumenschine (1994) and modified by Galán et al. (2009) and ourselves:

- Complete or classic notch: notch with two inflection points visible on the cortical surface and with a non-overlapping negative scar (Figure 2 A and A').
- Double opposing complete notches: two isolated notches situated on the two opposite sides of the diaphysis (Figure 2 C).
- Incomplete notch: a notch that has only one inflection point. The second is missing because the fracture line separates the notch into two parts or because a second notch overlaps this first notch (Figure 2 B).
- Double overlapping notches: two notches that share the same inflection point. They are on the same fracture edge; the inner conchoidal scar of one overlaps the other. In some cases, there can be more than two notches (Figure 2 D and D').
- Inverse notch or bifacial notch: notch characterized by both inner and outer conchoidal scars.
- Micro-notch: a notch measuring less than 1 cm.

We propose that a micro-notch can appear inside a notch. This micro-notch could localize the exact point of contact between the bone surface and the hard material during the blow. Likewise, a groove or a triangular pit can appear if the contact surface with the bone is sharp.

- Notch with internal conchoidal micro-notch on the edge of the notch.
- Notch with an internal triangular pit or a groove.

References: (Dauvois 1974; Bonnichsen and Will 1980; Binford 1981; Bunn 1981; Shipman 1981; Johnson 1985; Blumenschine 1988; Brugal and Defleur 1989; Noe-Nygaard 1989; Blumenschine and Selvaggio 1991; White 1992; Capaldo and Blumenschine 1994; Fisher 1995; Boulestin 1999; Costamagno 1999; Outram 2005; Domínguez-Rodrigo and Barba 2006; Pickering and Egeland 2006; Lyman 2008; Galán et al. 2009; Thiébaud et al. 2009; Rovira Formento 2010; Blasco et al. 2013; Masset et al. 2016; Vettese et al. 2017; Gifford-Gonzalez 2018).

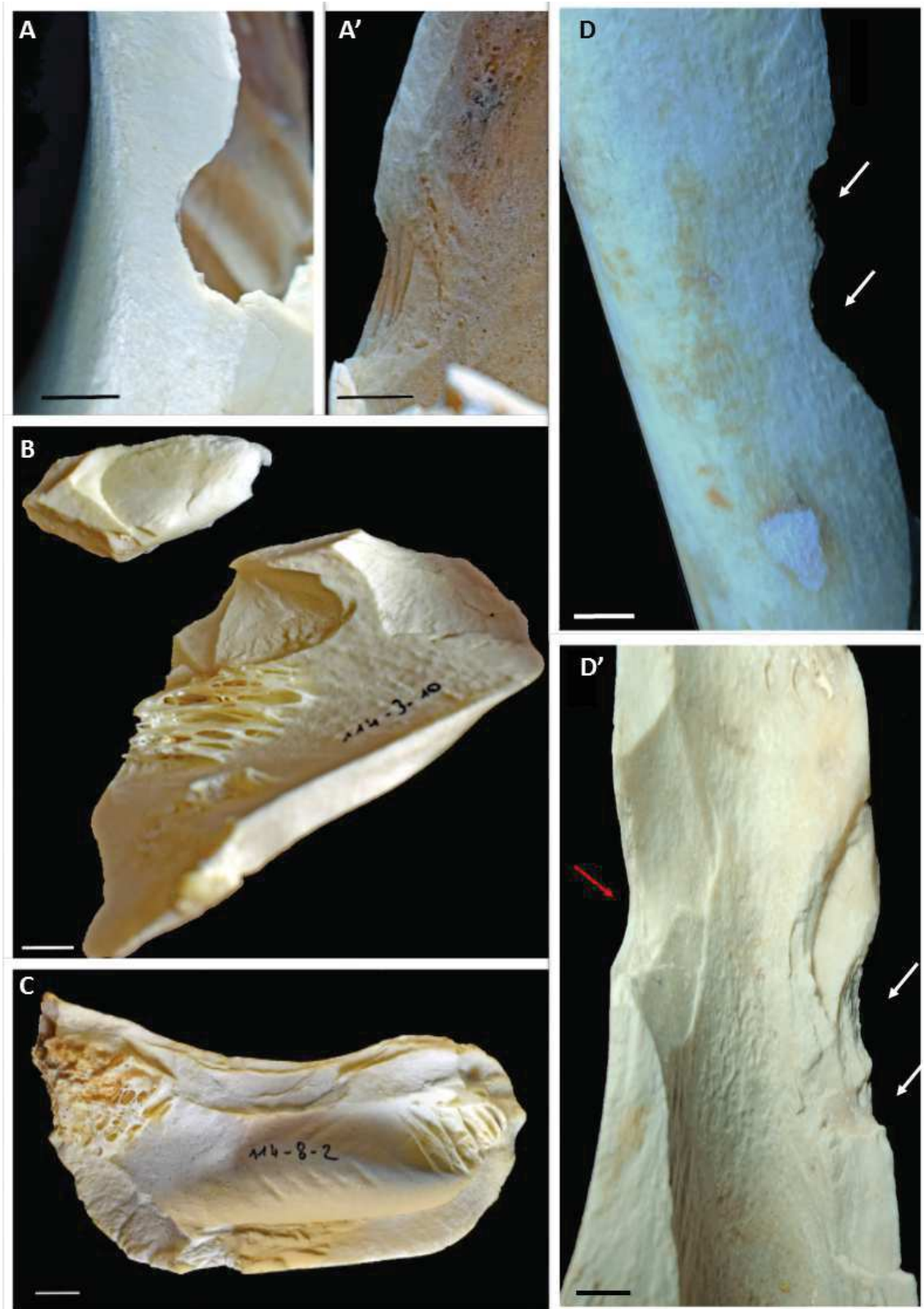


Figure 2: Direct percussion marks: some examples of percussion notches on experimental bones (adult *Bos taurus* species humerus and femur). (A-A') Complete percussion notch with an inner conchoidal scar (cortical (A) and medullary (A') views); (B) Incomplete percussion notch with the associated flake (medullary view); (C) Opposite percussion notches (medullary view); (D-D') Double percussion notches (white arrows) (cortical (D) view) and an opposite percussion notch (red arrow) at the double percussion notches (medullary (D') view). Bare scales represent 1 cm.

Percussion pit and groove

English: Chopper mark; chopping mark; chopping scar; deep puncture; grooves; isolated pits; percussion marks; percussion pit; pit; punched-out lesion; score.

French: Cupule; dépression ; zone d'écrasement.

Italian: Coppelle; sbrecciature; tracce da percussione; stigmati di percussione.

Spanish: Depresión; estigma de percusión; golpe; percusión; ranura de percusión.

German: Schlagnarbe.

Definition: Percussion pits are roughly round or sharp superficial pits that appear on the cortical surface of the bone (Figure 3). Sometimes they are associated with the abrasion of the cortical surface and even some micro-striations. The rebound effect may produce these marks without the formation of the fracture line.

We differentiate two types of pits modified from Mallye and colleagues (2012):

- Ovoid pit: a pit with a round shape. It could have a scaled area. This mark is due to the impact of a non-retouched cobble (Figure 3 C).

- Triangular pit or linear pit: a pit with a sharp shape (Figure 3 D).

Percussion grooves are superficial grooves appearing on the cortical surface of the bone. Their shapes are elongated ovals and in cross-section they are V-shaped. They are longer than pits. It is also called chopping mark (Figure 3 A).

References: (Shipman 1981; Blumenschine and Selvaggio 1988; White 1992; Fisher 1995; Peretto et al. 1996; Boulestin 1999; Costamagno 1999; Pickering and Egeland 2006; Lyman 2008; Galán et al. 2009; Thiébaud et al. 2009; Mallye et al. 2012; Blasco et al. 2013; Masset et al. 2016; Vettese et al. 2017; Gifford-Gonzalez 2018).

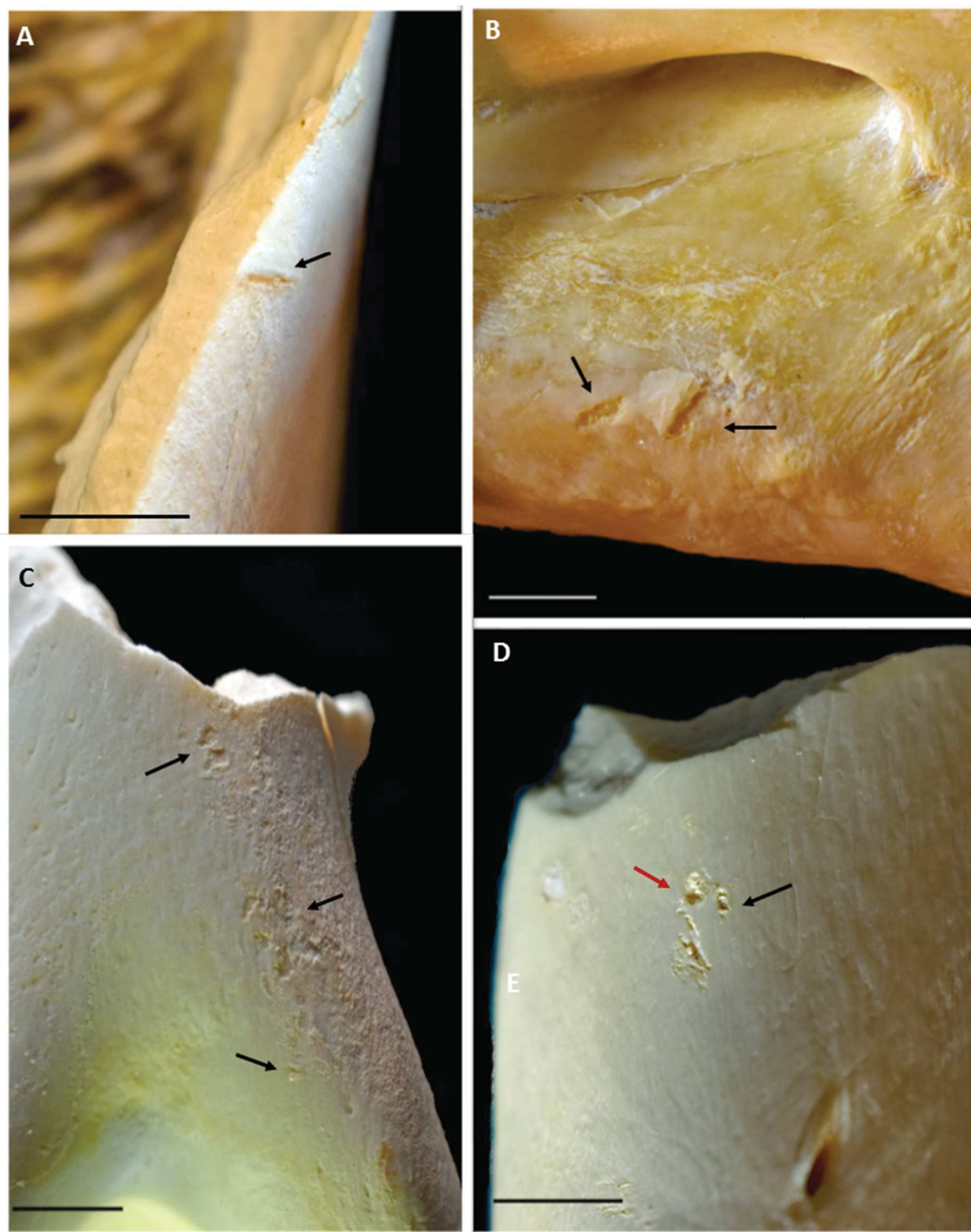


Figure 3: Direct percussion marks: some examples of percussion pits and grooves on experimental bones (adult Bos taurus species humerus and radio-ulna). (A-B) Percussion grooves; (C) Some ovoid percussion pits; (D) Triangular (red arrow) and ovoid (black arrow) percussion pits with related microstriations. Bare scales represent 1 cm.

6.2.2 *Traces consecutive to bone breakage*

Fractures and cracking

A fracture line is a breach in the cortical thickness of the bone. A fracture edge is located on each side of the fracture line.

The texture and the shape of the fracture edge can be indicative of the stage in the taphonomic sequence in which bone breakage occurred, i.e., ante-mortem, perimortem or post mortem. For example, perimortem green bone fractures are characterized by acute angles; they are curved with V-shaped fractures and smooth margins (Villa and Mahieu 1991). Regarding their curve, some green bone fractures can mimic marks related to percussion. Their shape can be similar to that of a notch or an outer conchoidal scar.

Incipient cracks are bone weaknesses running through the thickness of the fragment and stopping before breakage.

Ripple marks

English: Hackle marks; ripple marks; stress marks.

French: Glacis; hachure d'onde; marque en peignage.

Italian: Onde di percussione.

Spanish: Marcas concéntricas; marcas de stress; ondas; ondulación.

German: Schlagwellen.

Definition: Ripple marks or hackle marks are located at or near the bulb or platform. Dauvois (1974) considered that they were hatching waves originating from shock waves (Figure 4 B). For Johnson (1985), they indicate a dynamic impact. Ripple marks can occur on the fracture edge of the bone compacta, not only on the percussion flake. In this case, these marks could be made of stress 'relief'. These can also happen if the fracture is propagated round a tight corner in thick cortical bone. They are associated with green bone fractures.

References: (Dauvois 1974; Johnson 1985; Fisher 1995; Boulestin 1999; Pickering and Egeland 2006).

Peeling

English: Peeling.

French: Arrachement.

Italian: -

Spanish: Pelado; astillamiento; marcas de flexión.

German: Abschälen der Knochen-Oberfläche.

Definition: Peeling is a mark characterized by a roughened surface with parallel grooves or a fibrous texture due to the separation of two parts of a fresh bone when the fracture is not complete and still attached (Figure 4 C). White defined this trace for the first time in 1992. In addition, Pickering and colleagues (2013) defined three types of cortical peeling damage on rib related to their extent on bone surface: “classical peeling”, “general peeling” and “incipient peeling”.

References: (White 1992; Costamagno 1999; Pickering and Egeland 2006; Blasco et al. 2013; Fernández-Jalvo and Andrews 2016).

Pseudo-notch

English: Pseudo notch.

French: Pseudo-encoche.

Italian: Pseudo-incavo

Spanish: pseudo-impacto; pseudomuescas.

German: Pseudo-Schlagmarke; Pseudo-Schlagspur

Definition: The pseudo-notch is basically shaped like a notch but lacks its other characteristics. The two inflection points or the negative flake scar can be lacking. Its shape can be more angular and not semi-circular. They do not result from an impact during marrow extraction; but are formed by fractures or counterblows.

We follow a modified division established by Capaldo and Blumenshine (1994):

- Outer conchoidal scar: Conchoidal-shaped scar on the cortical surface (Figure 4 A). The semi-circular shape cuts the edge of a fracture line. This scar does not cut through the cortical thickness.

- Inner conchoidal scar: Like the previous type, but on the medullary cavity surface.
- Grouped micro-notches: Many micro-notches lined up on the fracture edge.

References: (Dauvois 1974; White 1992; Capaldo and Blumenshine 1994; Pickering and Egeland 2006; Thiébaud et al. 2009; Masset et al. 2016; Gifford-Gonzalez 2018).

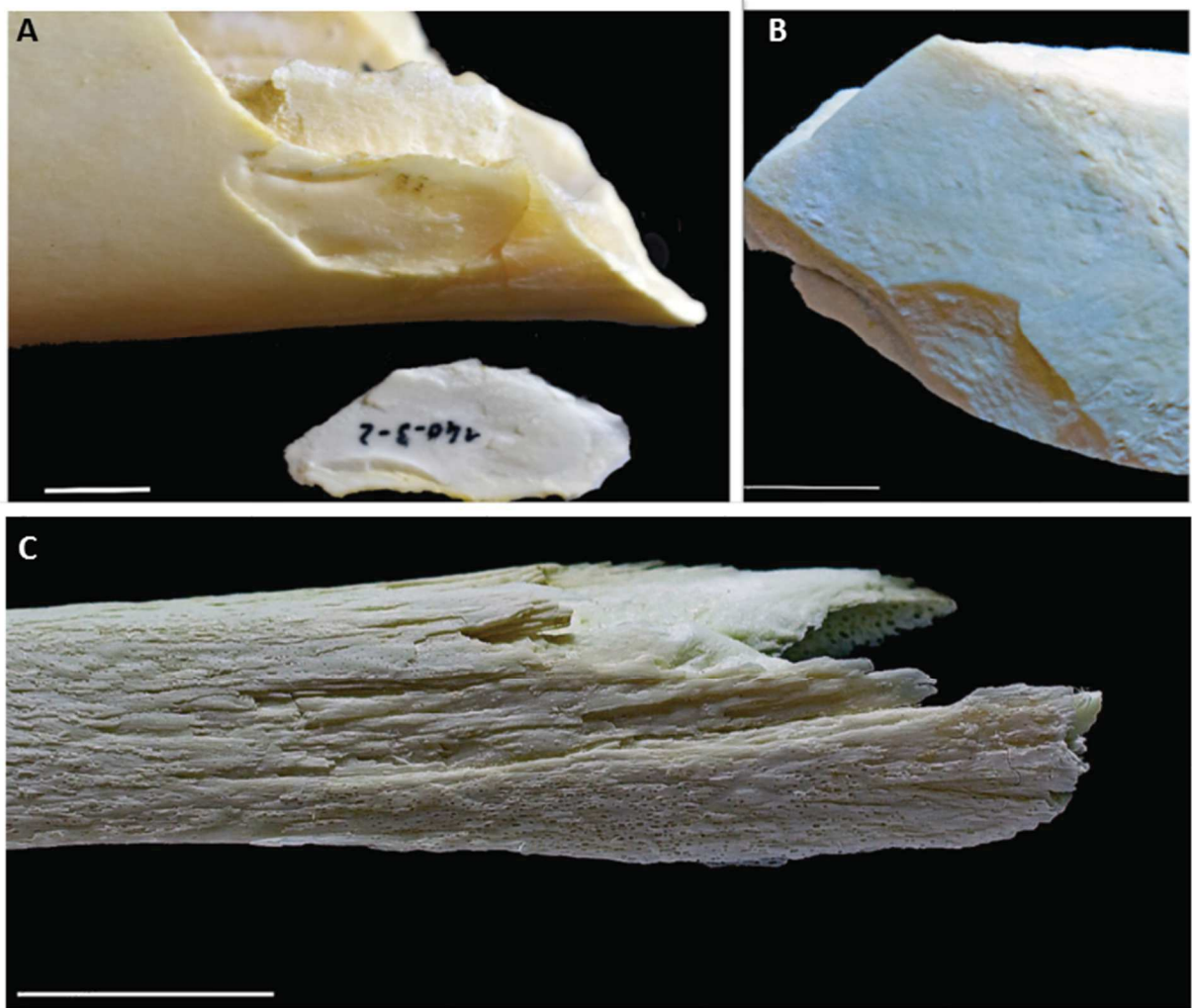


Figure 4: Auxiliary marks related to the marrow extraction: some examples of ripple marks, peeling and pseudo-notch on experimental bones (one radio-ulna and one humerus of adult *Bos taurus* species and one *Ovis capra tibia*). (A) Outer conchoidal scar with the related flake; (B) Ripple marks within outer scar; (C) Peeling. Bare scales represent 1 cm.

6.2.3 Striations related to the percussion marks

Scraping marks

English: Scraping marks

French: Marques de raclage.

Italian: Raschiature; tracce di raschiatura.

Spanish: Raspados.

German: Schabespuren

Definition: Scraping marks are made with the cutting edge of a lithic tool to remove muscles, tendons or the periosteum. Ethnological observations show that the Nunamiut, for example, remove the periosteum before the breakage of a long bone. These marks are long and parallel. They are thin, plural and more superficial than incisions. However, experiments have shown that the removal of the periosteum is optional for the breakage process (Galán et al. 2009; Vettese 2014).

References: (Binford 1981; Villa et al. 1986; White 1992; Galán et al. 2009); Vettese 2014.

Microstriations and striations

English: Anvil scratches; anvil striae; microstriations; percussion microstriations; percussor striae; random striae; striae fields.

French: Stries d'enclume; stries de percussion.

Italian: Tracce da percussione; stria da percussione; striature da percussione; stria da percussore; abrasioni da impatto

Spanish: Estrías de yunque; estrías de percusión; microestriaciones; microestriaciones de percusión.

German: Mikro-Schrammen

Definition: These marks originate from the roughness of an anvil or percussor (Figure 5). During the impact, they form when the cortical surface of the bone scrubs the surface of the anvil or the hammerstone. They are superficial, short and parallel. They are sometimes associated with percussion pits or notches.

References: (Blumenschine and Selvaggio 1988; White 1992; Fisher 1995; Boulestin 1999; Pickering and Egeland 2006)

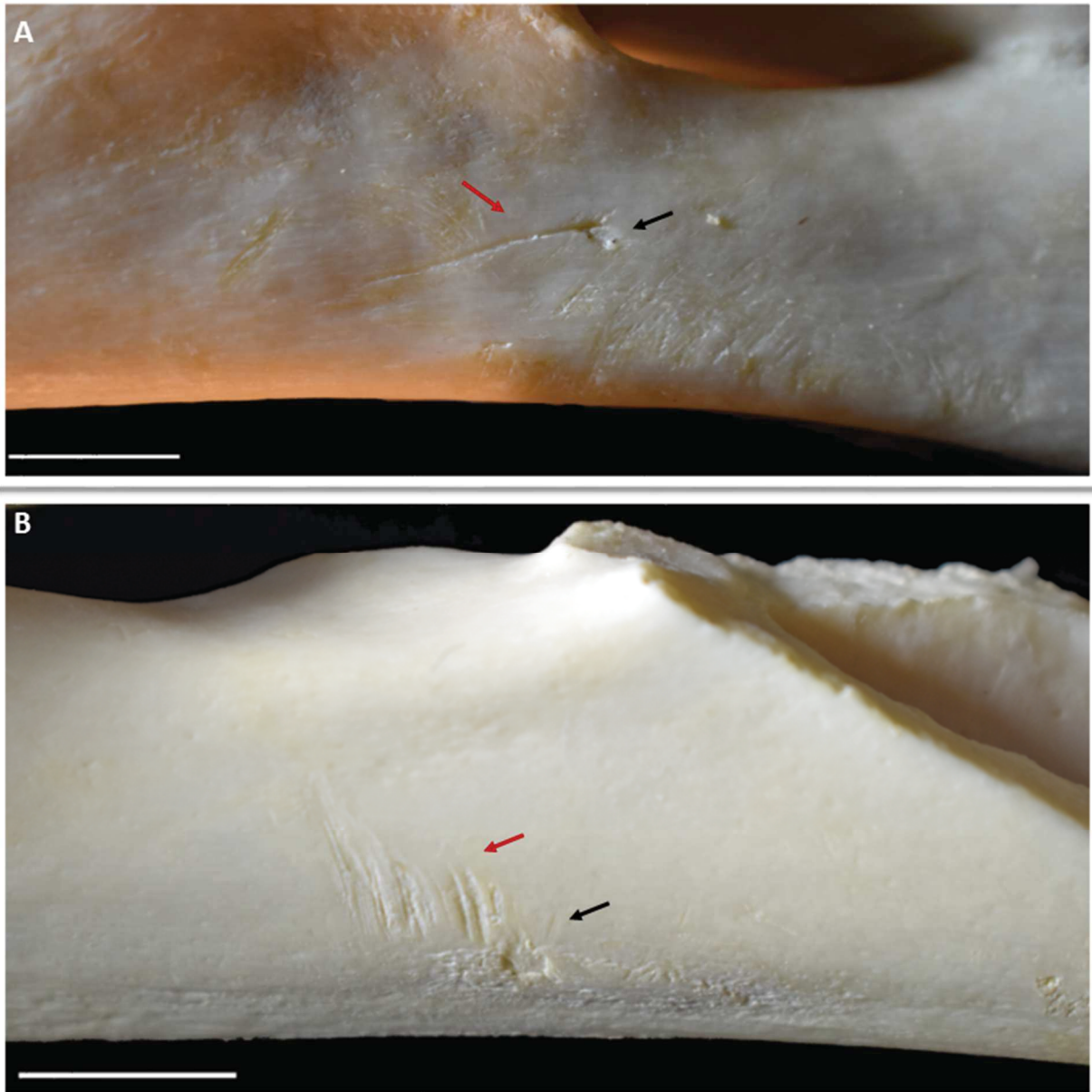


Figure 5: Auxiliary marks related to the marrow extraction: some examples of striations, micro-striations and scraping marks on experimental bones (one adult *Bos taurus* species radio-ulna). (A) Striation (red arrow) related with triangular percussion pit (black arrow), numerous micro striations associated; (B) Microstriations (red arrow) with associated ovoid percussion pit (black arrow). Bare scales represent 1 cm.

Conclusion

Through a historical perspective of the study of bone breakage in archaeological contexts, we have outlined two main problematics. First of all, the equifinality of the traces left on bones by different taphonomical agents and secondly, the multiple and arborescent terminology existing for identifying percussion marks.

Concerning the equifinality, the knowledge of the physical-chemical structure of large ungulate long bones enhances our understanding of the extrinsic and intrinsic factors that may

affect the marks. We also present the different techniques of marrow recovery to highlight the specificity of dynamic loading, taking into account the shape of the striking tools. Despite the numerous experimental and ethnological studies, it is still difficult to identify the techniques used based on percussion mark morphology.

For this reason, we propose a descriptive terminology for traces related to dynamic loading. We put forward a new classification to differentiate direct percussion marks *sensu-stricto* from the other traces formed during the marrow recovery process. Ongoing research will take into account percussion marks not as single traces but as a package of different sorts of marks in archaeological faunal assemblages. Considering percussion marks as a whole can bring to light patterns which otherwise go unnoticed, particularly in terms of spatial distribution. This research will facilitate the use of percussion marks in a more accurate and detailed manner for reconstructing hominin butchering practices.

Marrow processing can be considered as a hallmark of hominin adaptation to high energetic nutrition. Speth (1989) hypothesized that the main purpose of hunting or scavenging large mammals by early hominins would have been lipids and not proteins. He assumed they were able to extract "the precious lipids" of both the medullary cavity and the cancellous tissue of bones. Moreover, current work of Thompson et al. (2019 -p1.) proposes "an emphasis on percussion-based scavenging of inside-bone nutrients, independently of the emergence of flaked stone tool use". They suggest that the archaeologists might find evidence of percussion activity for marrow extraction predating the use of stone flakes in order to remove meat. The marrow could then represent one of the oldest animal nutrients recovered by hominins. Thus, the first anthropogenic traces could be percussion marks and not cut marks. Therefore, for understanding this basic nutritional behaviour it is imperative to appreciate bone breakage mechanics and traces resulting from marrow processing. Nevertheless, this field of research is still underestimated. Many studies tried to detail percussion techniques or focused on identifying various percussion traces, but our work has the merit of synthesizing it and proposing a solid nomenclature to rely on. Thus, the current study must be understood as a first comprehensive attempt to heal this breach.

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Chapitre III.

Travaux expérimentaux

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III. 1. Introduction

Dans ce chapitre nous présenterons les différents axes que nous avons développés en lien avec une vaste expérimentation menée dans les locaux du MNHN avec le soutien de l'entreprise Charal. Cette expérimentation a servi de base à un grand nombre d'analyses et de travaux variés qui ont pris la forme de deux articles, d'une présentation orale dans un congrès, mais aussi d'un mémoire de recherche de Master 2. En guise d'introduction à tous ces travaux, nous synthétisons ici les principaux axes de recherche, problématiques et résultats obtenus.

En premier lieu, nous reviendrons sur les problématiques qui ont permis la mise en place d'un protocole expérimental complexe s'intéressant à l'extraction de la moelle jaune en contexte intuitif (Chapitre III.2.). Puis, nous présenterons les résultats préliminaires d'une étude qui a fait l'objet d'une communication orale au *Ve International Congress of Experimental Archaeology* qui s'est tenu à Tarragone en 2017 (Chapitre III. 3.). Ce travail s'est intéressé à la localisation du premier coup donné pour chaque essai au cours de l'expérimentation. Puis, nous exposerons les résultats obtenus par l'analyse de la distribution des marques de percussion à l'aide d'une méthodologie d'analyse spatiale originale appliquée sur les os longs (SIG : Système d'Information Géographique) (Chapitre III. 4.). Cette approche a été mise en place dans le cadre d'une collaboration avec une stagiaire bénévole, T. Stavrova (co-direction D. Vettese, A. Borel et C. Daujeard), sur un échantillon réduit de 40 os, et a donné lieu à une publication dans la revue *Plos One* (Stavrova et al., 2019 ; Chapitre III.4. Publication n°2). Nous avons ensuite appliqué cette méthode à un plus grand échantillon (120 os), afin de tester la part d'intuitivité dans les gestes sur la base de zones percutées spécifiques le long des os longs (Chapitre III. 5. ; Publication n°3). Cette partie de nos recherches a fait l'objet d'un article qui sera soumis à la revue *Journal of Archaeological Method and Theory*. Enfin, de façon à mieux comprendre la production des marques de percussion sur les restes osseux et leur distribution, nous présenterons les résultats d'une expérimentation annexe dont le protocole visait à contraindre un maximum de variables. Ce travail a fait l'objet d'un mémoire de Master 2 (QP, MNHN) réalisé par Louis Chevillard (co-encadrement D. Vettese, A. Borel et C. Daujeard) (Chapitre III. 6.).

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III. 2. Présentation de l'expérimentation

III. 2. 1. Problématiques de départ

Notre définition de « traditions bouchères » se base sur la présence d'une systématisation des gestes bouchers, dont le modèle ne correspondrait pas à celui de pratiques intuitives. Dans cette optique il nous faut définir ce que nous entendons par « intuitivité » : manière qui consiste à procéder par intuition, sans avoir recours à aucune expérience préalable et sans connaissance directe de la pratique ou du geste. A partir de cette définition et dans la continuité des rares travaux antérieurs existant sur le sujet (cf. ci-dessous).

Dans leurs travaux, Blasco et al. (2013) ont mené une première expérimentation pour enregistrer l'emplacement et la distribution des marques de percussion sur les os longs en contexte intuitif. Ils ont ensuite comparé leurs résultats expérimentaux avec ceux obtenus sur des séries de faunes fossiles provenant de sites du Paléolithique moyen (Gran Dolina et Bolomor, Espagne). Deux techniques distinctes ont été utilisées lors de cette expérimentation : la technique de l'os lancé et celle du percuteur sur enclume. Les résultats de ces travaux montrent d'une part que les marques de percussion étaient peu nombreuses (en majorité une marque ou deux pour un maximum de quatre coups) et que les expérimentateurs au bout de deux ou trois essais sélectionnaient un emplacement préférentiel pour porter leurs coups.

Cependant, les résultats de l'expérimentation exploratoire que nous avons réalisée en collaboration avec I. Caceres durant ma mobilité de master en 2014 (IPHES Taragona), ont montré que l'extraction complète de la moelle pouvait nécessiter plusieurs coups à des emplacements différents sur la diaphyse, et ce même pour une personne expérimentée (Vettese, 2014). Malgré les très nombreuses références existant dans la littérature sur le thème de la fracturation et des marques de percussion, l'expérimentation de l'équipe espagnole (Blasco et al. 2013) était alors la seule qui prenait en compte l'intuitivité et la répartition des marques lors de la fracturation osseuse. Afin d'explorer ce nouvel axe de recherche et de tenter de répondre à la question des pratiques intuitives, nous avons donc décidé de réaliser une vaste expérimentation pour compléter ces résultats préliminaires.

Les différentes problématiques qui nous ont permis d'établir le protocole de cette expérimentation basée sur l'observation des gestes dans l'extraction de la moelle jaune en contexte intuitif sont les suivantes :

- Existe-t-il une manière préférentielle intuitive de fracturer les os longs d'un animal pour en extraire la moelle de façon à ce qu'elle soit consommable ?
- Peut-on mettre en évidence un modèle de distribution intuitif des marques de percussion ?
- Quelles sont les variables qui pourraient expliquer la présence ou l'absence d'un modèle intuitif ?
- Quelle est l'influence de la morphologie osseuse, de sa structure, de sa forme sur la manière dont un individu fracture un os ?
- Quel est l'impact des comportements individuels ?
- Quelles sont les données qu'il est possible d'utiliser pour étudier l'intuitivité dans une expérimentation contrôlée sur la fracturation osseuse en vue d'extraire la moelle jaune ?
- Un individu qui fracture une série d'os long développe-t-il une méthode propre ? Peut-on estimer au bout de combien d'essais un individu standardise sa manière de fracturer ?

III. 2. 3. Protocole de l'expérimentation menée au MNHN (février-mars 2017)

Afin de pouvoir comparer nos résultats expérimentaux avec ceux de nos échantillons archéologiques, nous avons choisi des ossements d'un animal ayant des caractéristiques communes avec les espèces présentes dans nos assemblages archéologiques : la vache (*Bos taurus*). Dans l'optique de répondre aux problématiques précédemment exposées et de façon à obtenir des résultats exploitables d'un point de vue statistique, chaque expérimentateur (35 au total) devait fracturer une série de dix os longs d'un même élément.

Les abattoirs de l'entreprise Charal ont fourni 400 os de vaches (Chapitre II.). Après réception des os au MNHN, les ossements ont été conservés durant moins d'une semaine dans un réfrigérateur à 4°C. Deux sessions ont été programmées (mars et mai 2017). Entre les deux sessions, les ossements non-fracturés lors de la première session sont restés au congélateur pendant les 40 jours, pour ensuite être décongelés trois jours avant la seconde session.

Pour des raisons d'homogénéité entre les séries et à cause de quelques abandons, seuls 367 os ont été fracturés. En amont de l'expérimentation de nombreuses données ont été récoltées sur chaque individu : âge, sexe, poids, main(s) préférentielle(s), connaissance en

anatomie et pratique sportive. Notre échantillon de volontaires était composé de 25 droitiers, six gauchers et quatre ambidextres, 18 hommes et 17 femmes. Leur âge moyen était de 33 ans (entre 21-64 ans). Les expérimentateurs mesuraient en moyenne 173cm (entre 190-156 cm) et pesaient en moyenne 70 kg (entre 56-110 kg). Cependant, il est à noter que si la parité homme-femme a été respectée dans l'ensemble de notre échantillon de volontaires, pour des raisons indépendantes de notre volonté, cette parité ne se retrouve pas pour chaque élément.



Figure 1: Illustration d'une volontaire et d'une observatrice lors de l'expérimentation. On note également sur cette photo les outils fournis: assiette, bâton, enclume et percuteur. Photographie D. Vettese.

Afin de ne pas influencer le choix de l'expérimentateur dans sa façon de disposer l'os avant fracturation, les ossements étaient présentés en pile désordonnée. Avant de commencer, le volontaire ne recevait qu'une seule instruction : « Vous devez casser cette série d'ossements pour en extraire le plus de moelle possible et de façon à ce qu'elle soit consommable ». Aucune démarche supplémentaire n'était imposée et aucune démonstration n'était faite. Ils étaient libres de procéder comme bon leur semblait. Pour fracturer l'os, nous ne fournissions qu'un galet de quartz non retouché (environ 2kg) et une enclume de calcaire parallélépipédique dont il pouvait disposer à leur convenance. Une assiette et des bâtons en bois leur étaient également proposés pour récolter la moelle. Une fois la plus grande quantité de moelle extraite selon

l'expérimentateur, l'expérimentation s'arrêtait. Le périoste des os n'était pas préalablement raclé. A la fin de chaque essai, tous les fragments d'un même os étaient récoltés et rassemblés dans un même sac avant d'être nettoyés puis analysés. Des observateurs, dont le seul prérequis était un minimum de connaissance anatomique osseuse, enregistraient des informations relatives au déroulé de l'expérimentation : la latéralité de l'os, la quantité relative de chair, si l'os avait été congelé préalablement ou non, la position de l'expérimentateur, la main utilisée pour donner les coups, la position de l'os, l'angle de frappe, le nombre de coups donnés et leur position relative sur l'os (cf. Figure 1, Chapitre II), le nombre de restes produits, le ressenti en difficulté sur une échelle de 1 à 5 (1 très facile à 5 très difficile) et la qualité de la moelle selon une échelle de 1 à 5 (1 non consommable à 5 consommable). Pour ce dernier critère, les observateurs devaient prendre en compte la présence de d'esquilles mélangés à la moelle. Ces informations ont été enregistrées sur des fiches préétablies (annexes). Une base de données appropriée a été créée afin de récolter toutes ces données. Chacune des expérimentations a été filmée et des photos des os avant et après fracturation ont été prises à chaque étape de la série (Figure2).

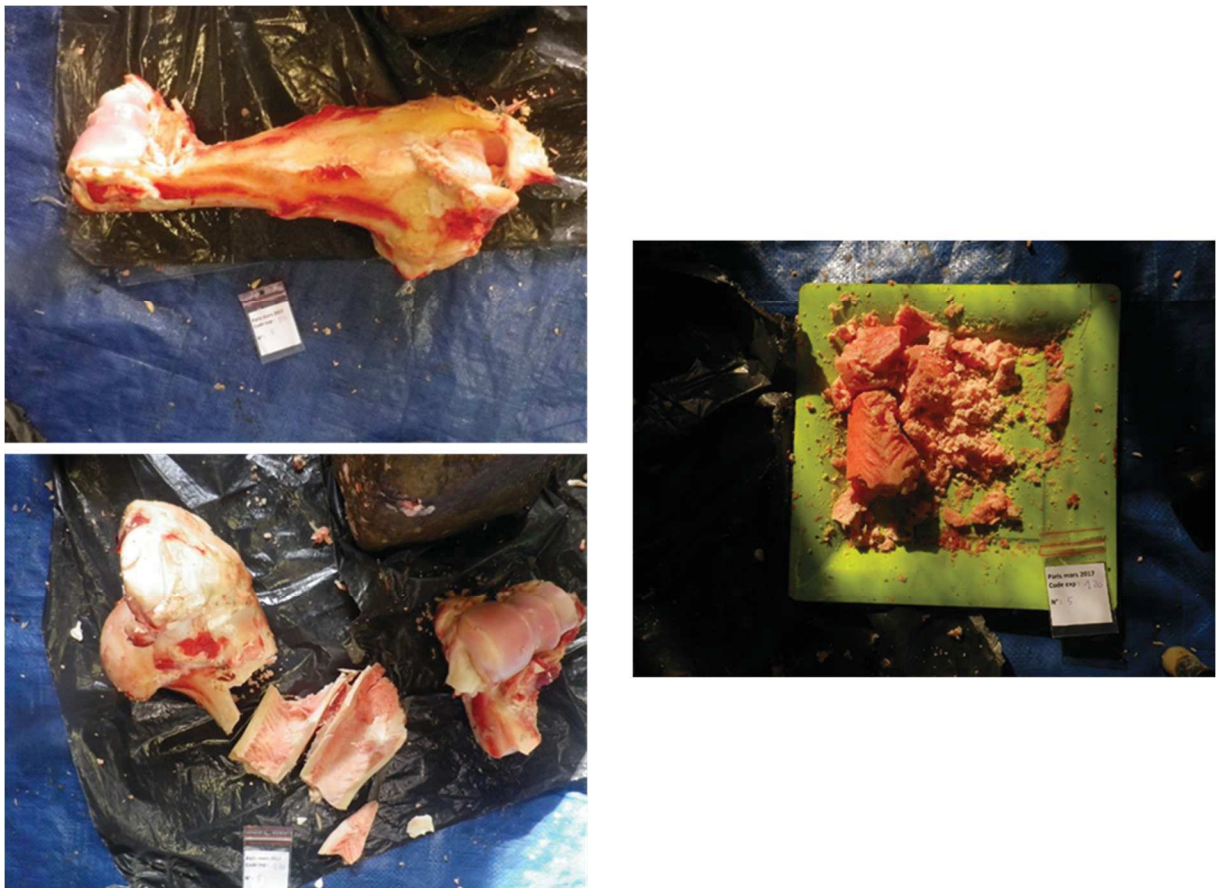


Figure 2: Exemple d'un humerus droit avant, puis après fracturation et la moelle qui en a été extraite. L'échelle blanche représente 10 cm. Photographie Juan Marin.

Dans le cadre de cette expérimentation, environ 1,4 tonne d'os ont été cassés, plus de 13 400 coups ont été donnés et plus de 7000 restes ont été produits et récoltés. Près de 55kg de moelle ont été extraits. En moyenne, extraire la moelle d'une série de dix os de vache prend entre deux à trois heures. Ce sont les radio-ulnas qui prennent le plus de temps. Nous disposons à ce jour de plus de 60h de vidéos illustrant les différentes manières sélectionnées pour casser les os longs et en extraire la moelle. Seuls trois volontaires n'ont pas fini leur série de dix os à casser. L'un s'est arrêté à neuf éléments fracturés (radio-ulna), l'une au cinquième (radio-ulna) et la dernière au troisième (humerus). Plusieurs petites blessures ont été constatées tels que des bleus dûs à des coups sur les mains et les doigts et des coupures légères dues à de petites esquilles d'os. Plusieurs volontaires ont signalé que dans les jours suivants l'activité, ils ont ressenti des douleurs musculaires (courbatures).

Le Service de Traitement Ostéologique (SPOT) du MNHN s'est chargé du nettoyage des restes de l'expérimentation. Les os ont été bouillis pendant 2 ou 3 heures, pour enlever la graisse et ramollir la chair, puis placés dans un four à 40°C dans une solution d'eau et de papaïne (enzyme de papaye) pendant 48 heures. Ensuite, ils ont été placés dans une solution d'eau et de perborate de sodium pendant 24 heures, avant d'être séchés à l'air. Le matériel est actuellement conservé à l'Institut de Paléontologie Humaine (Paris).

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III. 3. Où placer le premier coup ?

Résumé de la communication orale présentée au Ve International Congress of Experimental Archaeology (Tarragona, 26-29 octobre 2017).

Between intuitiveness and standardization:

an experimentation on marrow extraction process

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Long bone breakage by Neanderthals to extract marrow is noticed in many archaeological sites. Indeed marrow was a useful nutritional resource to many human groups, particularly during glacial and periglacial periods. Archaeological experiments concerning bone breakage may be useful to characterize percussion marks (nomenclature) or to identify Neanderthal breakage process thanks to the location of percussion marks. Here, we present an archaeological experiment to test the intuitiveness of the gestures during the marrow extraction process of long bones. For this experiment, 400 cow long bones (100 humeri, 100 radio-ulnas, 100 femurs and 100 tibias) were broken. The experimental series involved 35 individuals (mean= 33 years with s.d.=10.7) with no experience related to bone breakage (non-trained butchers or experimental archaeologists). Each experimenter fractured 10 long bones (same element) with an unretouched quartzite hammerstone and a limestone anvil. Before the beginning of the experiment, each experimenter received only one instruction: break the bones to extract the greatest quantity of marrow. They could use a wooden stick to extract the marrow after the breakage process. During each bone breaking activity, the posture and the gesture of the experimenters were noticed, as well as the position of the bones.

First results show differences according the type of elements in terms of breakage process difficulty, quantity of marrow and percussion location. We also observe inter-individual differences in the location of the percussion hits.

The comparison of the percussion marks location between the results of this experiment and some Middle Palaeolithic faunal series will permit to go further on the butchery know-how of Neanderthal groups.

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III. 3. 1. Résultats préliminaires sur les premiers coups

Lors de l'expérimentation, nous avons observé que les volontaires choisissaient avec soin la position de l'os et l'emplacement du premier coup. Ce choix était fait alors que l'os était intact, et que sa morphologie n'était pas encore modifiée par les premières fracturations. Les volontaires essayaient plusieurs positions avant d'en choisir une et de commencer à frapper l'os, testant sa stabilité sur le support choisi. Au fur et à mesure de la série d'os fracturés, il nous a semblé que la localisation des coups était le fruit d'une réflexion qui pouvait évoluer. Nous avons donc choisi de nous intéresser au premier coup donné pour chacun des os des séries réalisées lors de cette expérimentation. En effet, il nous a semblé que l'information de la localisation du premier coup était un moyen efficace d'approcher l'intuitivité dans la fracturation osseuse. D'une part, nous avons observé si un individu changeait l'emplacement du premier coup en fonction de l'expérience acquise lors des différents essais de fracturation au fur et à mesure de sa série. Et d'autre part, nous avons testé plusieurs variables pour évaluer l'influence de plusieurs variables sur la localisation de ce premier coup : l'individu, son sexe, l'élément, sa latéralisation ou encore le nombre d'essai au sein de la série.

L'enregistrement des données a été effectué à partir des vidéos prises lors de l'expérimentation. L'emplacement du premier coup a été enregistré selon la zone percutée. En tout, neuf séries de chaque élément (humérus, radio-ulnas, fémurs et tibias) ont été prises en compte pour cette analyse. Sur les 367 essais, six prises de vue n'ont pas permis d'enregistrer la localisation du premier coup. Dans ce cas, nous avons considéré la donnée manquante et nous l'avons écartée de l'analyse.

Aucun des éléments étudiés ne présente de zone spécifique ayant été systématiquement frappée au premier coup, et ce pour l'ensemble des individus. Cependant, il est possible de noter quelques tendances avec des zones plus fréquemment frappées. Par exemple pour le fémur, la zone p3a (portion médiale antérieure) présente un plus grand nombre de coups.

Afin d'explorer nos données et tester l'influence des variables telles que la face ou la portion de la diaphyse portant une marque, nous avons effectué des Analyses à Correspondance Multiple à l'aide du logiciel R et des bibliothèques Factomin'R, Factoextra et Ggplot (R Core Team, 2019). Les résultats montrent que la variable qui influence le plus la localisation du premier coup chez les individus sans expérience est le type d'élément fracturé (Figure 4). La latéralité de l'élément ne semble pas, quant à elle, contraindre cette localisation. Par ailleurs, il semble y avoir des choix propres à chaque individu dans la sélection de l'emplacement du premier coup. Cependant, ces résultats exploratoires ne nous permettent pas d'évaluer si cette variation

pourrait être due au fait qu'un individu ait cassé toujours le même os car cette variable influence fortement notre jeu de données. Il pourrait donc être intéressant de tester les éléments indépendamment les uns des autres. En outre, le sexe des individus ne semble pas avoir joué dans le choix de l'endroit où le premier coup a été donné. Pour ce dernier résultat, la parité n'étant pas respectée strictement pour chaque élément, une analyse plus fine des données devra être réalisée pour le vérifier. Pareillement, l'avancée dans l'expérimentation ne semble pas influencer non plus l'emplacement du premier coup. Les individus continuent en général de frapper l'os au même endroit au fur et à mesure des essais dans la série de dix os.

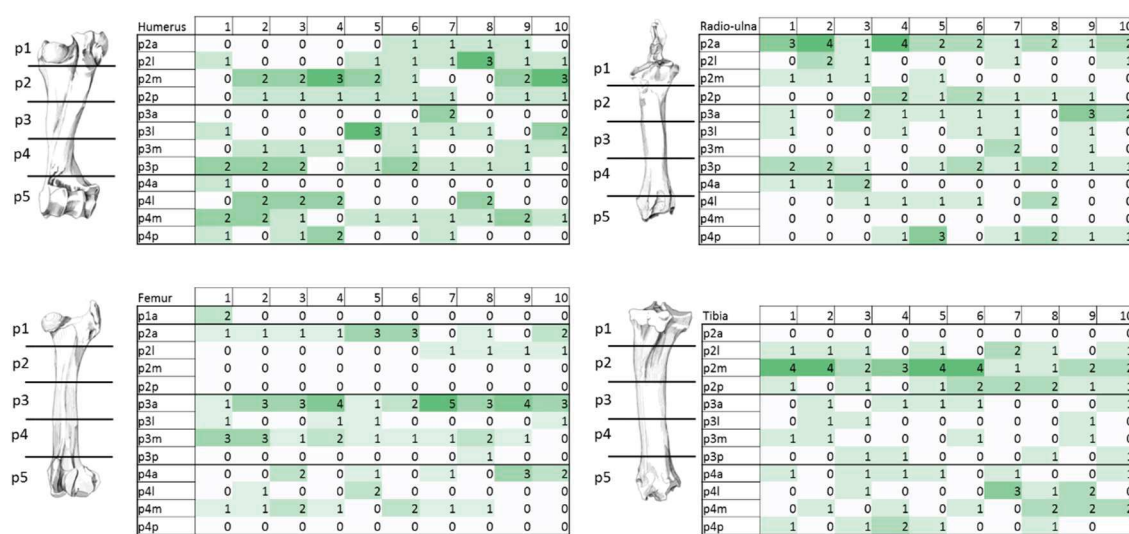


Figure 3: Nombre de fois où le premier coup a été porté sur une zone d'os selon le nombre d'essai pour chaque élément pour l'ensemble des volontaires (N=35). Plus la couleur des cases est foncée, plus le nombre d'observation dans cette zone est importante.

Bien que préliminaires, ces résultats sur la localisation du premier coup sont prometteurs. Ils montrent que l'emplacement du premier coup en contexte intuitif semble avant tout dépendre de l'élément, peu importe sa latéralité et à moindre mesure des particularités individuelles des volontaires. Il serait intéressant de tester à l'avenir la variation entre les individus ayant fracturé un même élément, et de comparer les résultats avec ceux de volontaires plus expérimentés, ayant développé une certaine habileté pour fracturer les os afin de récupérer la moelle. Il serait également intéressant d'approfondir les données enregistrées au moment de l'étude en laboratoire pour mieux comprendre le rôle des contraintes morphologiques de chaque os long : structures, formes ou densités osseuses. Enfin, confronter ces résultats avec ceux de l'ensemble des données récoltées lors de l'expérimentation, permettra de mettre en perspective l'emplacement des premiers coups avec celui de la totalité des coups donnés, puis dans un second

temps, avec la localisation des marques de percussion produites par ces coups. Cette étude montre qu'il s'agit là que d'une infime partie de tout ce qu'il est possible de faire à partir des vidéos enregistrés au cours de l'expérimentation.

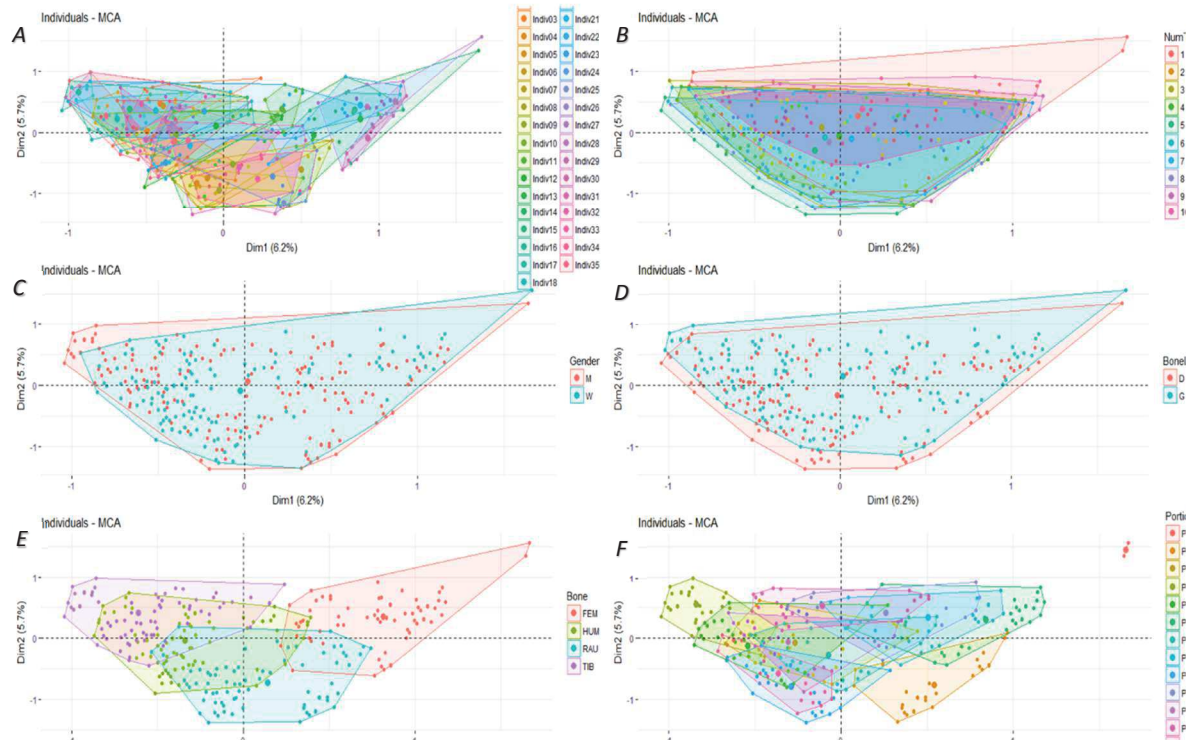


Figure 4: Analyse de correspondance multiple à partir de la localisation du premier coup pour l'ensemble des expérimentateurs. A- regroupement par individu ; B- regroupement par numéro d'essai ; C- regroupement par sexe des expérimentateurs ; D- regroupement par latéralité des ossements ; E- regroupement par élément et F- regroupement par localisation du premier coup sur la diaphyse.

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III. 4. Analyse spatiale (SIG) des marques de percussion

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A GIS based approach to long bone breakage patterns derived from marrow extraction

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In archaeological assemblages the presence of percussion marks, on the surface of long bones, is an indicator of long bone marrow extraction. The form, quantity and distribution of percussion marks are analysed to gain a better understanding of the marrow extraction process. Patterns of bone percussion damage in archaeological assemblages may highlight standardized actions, possibly related to butchery traditions. However, additional factors could underlie these patterns and should also be considered. In this article we test intuitiveness as a factor in appearance of percussion mark patterns, to see if patterns can appear when bones are being fractured without prior experience with bone fracture properties. To test this hypothesis, for this study we selected a sample of 40 cattle (*Bos taurus*) long limb bones from a large bone breakage experiment (400 long limb bones), where participants had no previous experience in bone breakage and may thus have broken bones intuitively. We used Geographic Information System (GIS) software to analyse the distribution of percussion marks. Using ArcGIS Spatial Analysts tools, we identified and quantified significant concentrations of percussion marks. Results show that percussion mark patterns emerge for the same bone element, and that specific sides and zones were recurrently selected by experimenters. The distribution of patterns varies among the different long bone elements, and we attribute this variance to an adjustment to bone morphology. In addition, we calculated and identified bone damage patterns resulting from hammerstone percussion. Crossing bone survivorship with percussion mark patterns enabled us to recognise and evaluate the effects of fragmentation and surface visibility in controlled experimental conditions. The GIS method facilitates comparisons between different variables and provides a sophisticated visual representation of results. Enlarging the sample will allow to constitute a more substantial analogous model for fossil assemblages

Key-words: GIS, bone breakage, experimental archaeology

*Approche techno-culturelle de la fracturation des os longs chez les Néandertaliens (Sud-Ouest de l'Europe, MIS 5-3) :
une systématisation des gestes ?*

III. 4. 1. Résumé long en français

Au sein d'un assemblage archéologique, la présence de marques de percussion sur les surfaces osseuses et des os longs notamment, est caractéristique d'une fracturation anthropique afin de récupérer la moelle. De nombreux travaux se sont intéressés à l'analyse de leur forme, de leur quantité ou de leur distribution, afin de mieux comprendre les processus d'extraction de la moelle par percussion. De récentes études ont mis en évidence des modèles de distribution de ces traces de percussion révélant des pratiques standardisées et par là même la présence de traditions bouchères spécifiques à un groupe. Cependant, de nombreuses variables peuvent être à l'origine de l'apparition de ces modèles de distribution standardisée. L'un de ces facteurs pourrait être la manière intuitive d'aborder l'os pour un individu n'en ayant jamais fracturé, influencée par la morphologie spécifique des os longs. Ainsi, dans cet article, nous avons voulu tester cette hypothèse grâce à l'étude d'un échantillon de 40 os longs de vache (une série de 10 humerus, 10 radio-ulnas, 10 tibia et 10 fémurs de *Bos taurus*) provenant d'une importante expérimentation (400 os au total) ayant impliqué des volontaires sans expérience préalable à la récupération de la moelle d'os longs. Par conséquent, chaque séries d'os étudiées a été fracturée de manière intuitive par un seul individu.

En outre, l'enregistrement précis de la localisation des impacts de percussion et leur visualisation sont essentiels pour interpréter les données expérimentales comme archéologiques. Dans cette optique, le travail de T. Stratova (dir. D. Vettese, A. Borel et C. Daujeard) s'est révélé essentiel dans l'étude des résultats de cette expérimentation sur l'intuitivité. Les objectifs de ce travail ont été d'élaborer un protocole standard et efficace d'enregistrement spatial des marques de percussion à l'aide d'un logiciel de SIG (Système d'Information Géographique) et de proposer une nouvelle méthode d'analyse de ces marques. Il a été ainsi possible de tester des hypothèses liées à la fracturation pour extraire la moelle de façon intuitive. Nous avons utilisé un logiciel d'analyse spatial utilisant le Système d'Information Géographique (SIG) pour analyser la distribution des marques de percussion. En utilisant ArcGIS Spatial Analyst Tools, nous avons identifié et quantifié des concentrations significatives de marques de percussion. Cette méthode novatrice permet d'illustrer visuellement et avec pertinence la distribution des marques de percussion sur les ossements et d'identifier les zones frappées de manières récurrentes.

Dans cette optique, chaque fragment a été dessiné sur un modèle en deux dimensions pour chaque os. Ce modèle est divisé en quatre faces (Figure 5). Puis à partir des fragments dessinés, chaque marque de percussion a été reportée comme un point sur le logiciel. Puis, nous avons attribuées le code suivant : les marques d'écrasement sont représentées par des étoiles rouges, les dépressions et les sillons de percussion sont représentés par des losanges noirs et

enfin, les encoches et éclats adhérents sont représenté par des ronds gris (Figure 6). Les éclats qui ont pu être remontés n'ont pas été pris en compte car ils se situaient au même emplacement que les encoches dont ils sont le positif (Chapitre II). Une fois toutes les marques de percussion dessinées pour chaque élément d'une série, toutes ces marques ont été combinées sur un même calque avant de procéder à l'analyse de points chauds optimisés (Figure 7). Les résultats de l'analyse de points chauds optimisés permettent de visualiser en rouge les zones de concentration significatives et en bleu les points froids (Figure 8).

Nos résultats ont montré l'émergence de modèles de distribution de ces traces. En outre, ces modèles varient d'un élément à l'autre, suggérant une possible adaptation des individus à la morphologie spécifique de chaque os long comme nous avons pu le voir précédemment (Chapitre III. 3.). Par ailleurs, dans notre étude nous avons caractérisé les marques typiques de percussion produites lors de l'utilisation de la technique de percussion à l'aide d'un percuteur sur une enclume. Nous avons aussi croisé les données issues à la fois du taux de survie des éléments avec les modèles de distribution identifiées, ce qui nous a permis de quantifier les effets de la fragmentation (perte de matériel) et d'évaluer la visibilité des surfaces dans les conditions d'une expérimentation contrôlée.

De plus, un des apports majeurs de ce travail a été de présenter plusieurs analyses spatiales possible à l'aide de ce logiciel (*Kernel density analysis, Average Nearest Neighbour Distance and Hot Spot Optimized analysis*) et d'en montrer la pertinence en fonction de la question posée. Dans le cas de l'analyse de répartition des marques de percussion sur les quatre faces de l'os, la méthode la plus efficace s'est révélée être celle des *Hot Spot Optimized analysis* (ou Analyse de points chauds optimisés), car elle prend en compte toutes les faces osseuses ensemble. Cette étude a montré l'importance de la morphologie des éléments, dans l'apparition de modèle intuitif, à partir de l'analyse de la distribution des marques de percussions. Sur la base des conclusions de cet article, nous avons pu élargir l'échantillon étudié par cette méthode afin d'évaluer si l'influence des comportements individuels pouvait avoir un poids plus ou moins important par rapport à la morphologie osseuse dans la répartition des marques de percussion.

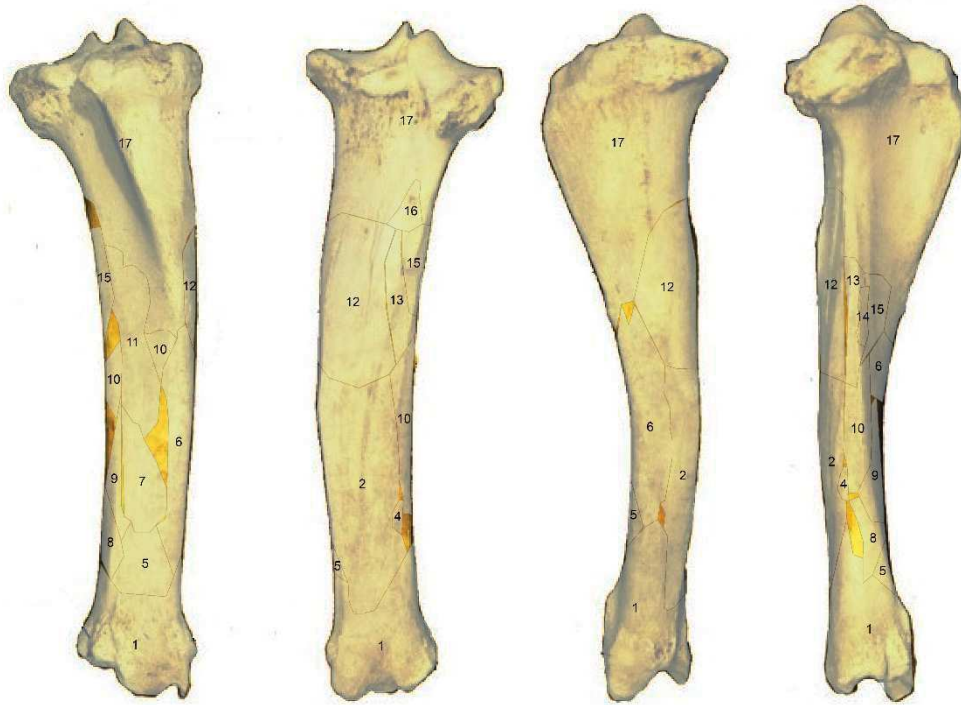


Figure 5: Dessin des restes de l'os n° 3 fracturé par l'individu n°10 sous SIG



Figure 6: Dessins des marques de percussion de l'élément n°3 fracturé par l'individu n°10 sous SIG

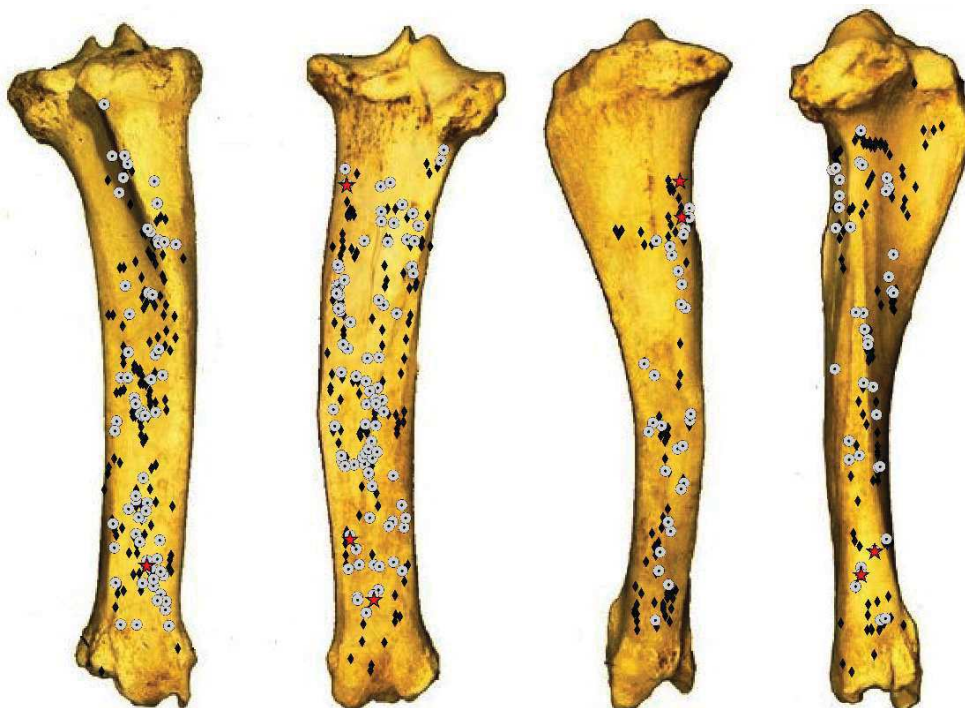


Figure 7: Toutes les marques de percussion de tous les éléments de la série fracturé par l'individu n°10 combinées sur une même illustration.

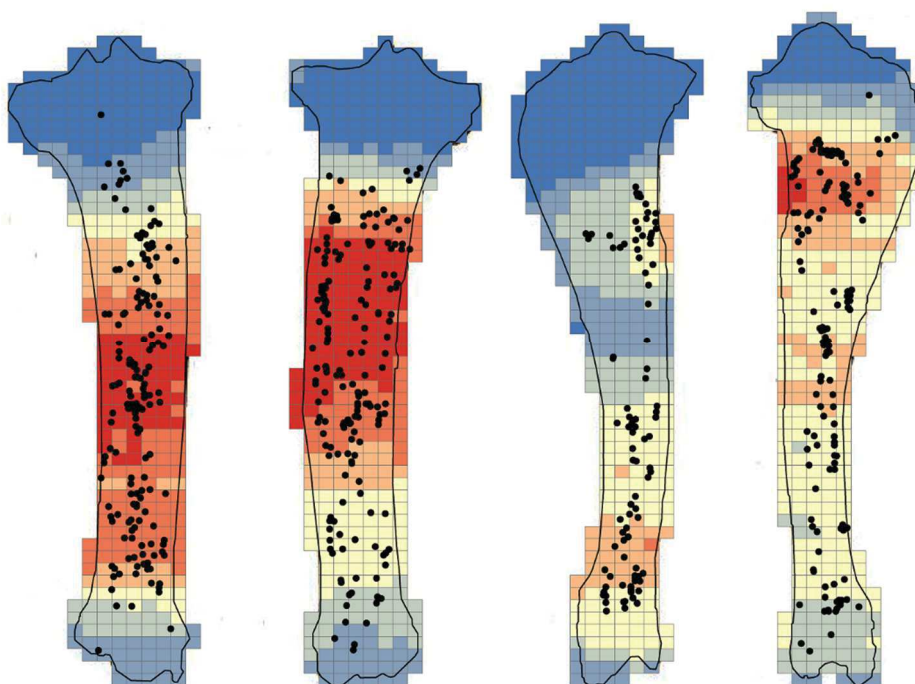


Figure 8: Illustration de l'analyse de points chauds combinés de toutes les marques de percussion de la série fracturé par l'individu n°10.

*III. 4. 2. Publication n°2***Full Title: A GIS based approach to long bone breakage patterns derived from marrow extraction****Short title: GIS and percussion mark patterns**T. Stavrova^{1*}, A. Borel¹, C. Daujeard¹, D. Vettese¹,¹Histoire Naturelle de l'Homme Préhistorique (HNHP, UMR 7194), Sorbonne Universités, Muséum national d'Histoire naturelle (MNHN), Homme et Environnement, CNRS, Université de Perpignan Via Domitia, Institut de Paléontologie Humaine, 1 rue René Panhard, 75013 Paris, France

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In archaeological assemblages the presence of percussion marks, on the surface of long bones, is an indicator of long bone marrow extraction. The form, quantity and distribution of percussion marks are analysed to gain a better understanding of the marrow extraction process. Patterns of bone percussion damage in archaeological assemblages may highlight standardized actions, possibly related to butchery traditions. However, additional factors could underlie these patterns and should also be considered. In this article we test intuitiveness as a factor in appearance of percussion mark patterns, to see if patterns can appear when bones are being fractured without prior experience with bone fracture properties. To test this hypothesis, for this study we selected a sample of 40 cattle (*Bos taurus*) long limb bones from a large bone breakage experiment (400 long limb bones), where participants had no previous experience in bone breakage and may thus have broken bones intuitively. We used Geographic Information System (GIS) software to analyse the distribution of percussion marks. Using ArcGIS Spatial Analysts tools, we identified and quantified significant concentrations of percussion marks. Results show that percussion mark patterns emerge for the same bone element, and that specific sides and zones were recurrently selected by experimenters. The distribution of patterns varies among the different long bone elements, and we attribute this variance to an adjustment to bone morphology. In addition, we calculated and identified bone damage patterns resulting from hammerstone percussion. Crossing bone survivorship with percussion mark patterns enabled us to recognise and evaluate the effects of fragmentation and surface visibility in controlled experimental conditions. The GIS method facilitates comparisons between different variables and provides a sophisticated visual representation of results. Enlarging the sample will allow to constitute a more substantial analogous model for fossil assemblages.

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Introduction

Over the past decades, archaeology and human behaviour studies have progressively incorporated research tools and analytical approaches from geospatial sciences. More than 30 years ago, the term GIS (Geographic Information System) was introduced to archaeology [1], and its application to the field has received mixed reviews over the years. Numerous articles discuss its effectiveness and advantages but also the uncertainty of the system [2-5]. However, since the late 2000s, GIS has rapidly gained momentum and is now an important asset to the archaeologist's tool set.

A GIS is a computer system capable of assembling, storing and manipulating, analysing and displaying geographically referenced information, i.e. data identified according to their location [6]. As stressed by many other definitions [7-9], the key word in GIS is geography and working with this system requires the terrestrial projection of data, meaning a system of coordinates in space that can correspond to latitudes and longitudes. Still, researchers from different fields grasped the potential of the software for non-geographical data and recent studies have used the system in an alternative way to apply the analytical capabilities of GIS to their subjects [10-12]. In a similar manner, we used GIS to illustrate and analyse the distribution of percussion marks produced during bone marrow extraction. The application of GIS to bone was introduced to archaeology by Marean and colleagues [13] to calculate the MNE based on anatomically overlapping specimens. All specimens are digitally drawn in vector mode over templates and then converted into pixels. The maximum number of pixel overlaps detected by the software indicates the MNE. The digitization of the method automated the process of MNE counts and made it appropriate for large assemblages which are otherwise difficult and time consuming to study. This innovative approach received a lot of attention. Lyman [14] argued that MNE calculation with the software could be easily biased by a lack of precision during the drawing of specimens. Others found it valid and continued to develop and adapt the method to more recent versions of GIS [15] and expand its applicability to the analysis of cut marks [16-17].

More recently, Parkinson and colleagues [18-20] proved the software to be well suited to documenting gross bone damage and tooth mark distribution in carnivore-modified assemblages. Spatial point pattern analysis, within GIS, indicates the distribution of tooth marks with greater resolution than previous methods. This allows comparisons with bone portion data. Parkinson's work complements a series of studies that have been developing methodologies for the past three decades to differentiate between human and non-human carnivore modifying agency [21-27]. Her experimental work analysing carnivore marks with GIS provides analogous models for the interpretation of zooarchaeological assemblages and helps to identify the modifier or modifiers and

their order of access. In recent years, many archaeological and paleoanthropological research teams have conducted bone breakage experiments subsequent to recurrent comments that bone fracturing and its diagnostic features (pits, notches, adhering flakes and crushing marks) are underexplored. Experiments and consequently developed methodologies broaden the possibilities and provide venues to explore bone breakage processing intensity and butcher investment [28], distinguish grease rendering from marrow extraction [29], and identify cultural patterns in bone breakage processes [30-34]. Recently, Blasco and colleagues [30] have argued that systemized patterns of long bone breakage for recovering marrow can help to identify butchery traditions in Neanderthal groups. To further the subject, of Neanderthal butchery know-how, Vettese [32] conducted a bone breakage experiment (400 long bones) in 2017 with participants that had no previous experience in bone breakage. The main aim of the experiment was to test whether recurrent percussion mark patterns will appear on the bone surface and if so to what extent, when the experimenters have no preconceived concepts on how to perform the task i.e. they will perform the task based on their intuition.

For this study, we selected a sample from this large experimental assemblage to analyse percussion mark patterns with GIS. We adapted and expanded the methods developed for GIS to a recent and updated version of the ArcGIS software (ArcMap 10.4) to explore and demonstrate some of the analytical possibilities available with this software when applied to percussion marks. More precisely, we set out to:

- Develop an effective GIS protocol to standardize the documentation process (database and visual representation) for fragments and percussion marks deriving from marrow extraction from long limb bones.
- Create an analytical workspace that allows a spatial link between the non-geographic database and its visual representation.
- Explore GIS abilities to record, quantify and illustrate bone fragments and bone survivorship.
- Explore new analytical methods to illustrate, quantify and analyse percussion marks and patterns of percussion marks.
- Test different hypotheses related to intuitive fracturing.
- Choose a model that can provide valuable insights for analogous archaeological assemblages.

Here, we do not examine the issue of how to diagnose or define percussion marks. Rather, our goal is to address the issue of how to record and then analyse them using GIS and ultimately

quantify the sample and concentrations of percussion marks for meaningful behavioural analysis, through comparisons with other modern control assemblages or archaeological assemblages.

Material and methods

Material

The studied sample is composed of 40 long limb bones from adult *Bos taurus* species. A series of ten bones was selected from the following elements: humerus, radius-ulna, femur and tibia. Bones were supplied by a slaughterhouse where carcasses were defleshed by a professional butcher. Metapodials are absent from the experiment as they were cut into two parts during the defleshing process, and were thus useless for this experiment.

Non-trained experimenters broke a series of ten long bones to a sufficient extent to remove all marrow (Table 1). Bones were broken with a non-modified quartzite hammerstone (pebble) against a limestone anvil. The periosteum was not removed prior to marrow removal. The experimental bone breakage was performed in a designated area, property of the Muséum National d'Histoire Naturelle, for which all necessary permits were obtained.

After breakage, all the fragments of each element were collected in a single bag associated with an identification code. This code provides information concerning the series and element numbers, which facilitated later identification and refitting. Broken bones were cleaned by the Service of Osteology and Taxidermy Treatment (SPOT) of the National Museum of Natural History of Paris (MNHN). Each bone was treated separately to avoid the loss of small fragments and dissociation from identification codes. Finally, we labelled each fragment with a permanent marker.

Table 1. General information regarding volunteers and bone elements

<i>Volunteer sex</i>	<i>Volunteer age</i>	<i>Element</i>	<i>Series n°</i>	<i>Number of right elements</i>	<i>Number of left elements</i>
<i>Female</i>	29	Humerus	1	3	7
<i>Male</i>	40	Radius-ulna	2	6	4
<i>Male</i>	25	Femur	3	6	4
<i>Male</i>	30	Tibia	4	4	6

Methods

Template/Image preparation and georeferencing

As a base for GIS analysis, we used photographic images representing the four-sided visualization of bone elements [35]. The templates were georeferenced in GIS. As bones are not part of geography, reference coordinates are assigned arbitrarily but they should be specified so that, data can be shared and made compatible with other GIS systems if needed. We used the WGS1984 Greenwich projection. A GIS polygon layer was created over each bone image (Fig 1), replicating the bone silhouette from four views (anterior, lateral, medial and posterior). These templates represent the basis for all further analysis. It is important to note that the area defined by these templates does not reflect the actual bone area. The measurements of all bones from the same element show slight variation and when projected with the software, for the purpose of standardization and superposition of layers, their metric measurements undergo deformations.

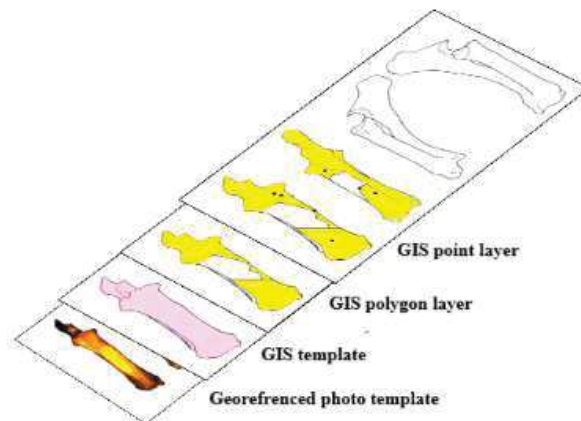


Fig 1. Superposition of GIS layers drawn over the photographic template

Bone refitting and analysis

We examined each specimen and percussion mark individually and in relation to each other through systematic bone refitting for every element. Each fragment was measured (mm) and weighed (g), then labelled with its series number, element number and an individual specimen number (e.g., 1-1-1= series number-element number-fragment number). Bone refitting generates more precise drawing and localization of fragments and percussion marks in GIS. It also enhances the identification and comprehension of percussion marks, as in some cases, a mark can be obliterated by subsequent blows in the same area, which may be required to fracture the bone completely. When refitting two or more fragments, at times we re-evaluated our judgment based on the analysis of a single fragment, i.e., a single notch can be divided and appear on two (or more) fragments. With refitting we count this as a single percussion mark.

We observed all specimens for surface modifications under a strong light (60 W), first with the naked eye; then with a 15-20X lens. Identification and characterization of percussion modifications are based on descriptions and illustrations of bone surface modifications e.g., [23] [28] [31-32], [36-38].

We recorded the following modifications regrouped in this study under the term percussion marks:

- Percussion pits,
- Notches,
- Adhering flakes,
- Crushing marks,
- Cortical conchoidal scars.

Pseudo-notches and peeling were not taken into consideration because they are not direct marks but successive results of fractures. We recorded the marks due to blows and counterblows. We did not observe chop-marks in our sample due to the roundness of the hammerstone pebble and in spite of the anvil's sharp edge.

Drawing fragments in GIS

All identifiable fragments are digitally drawn in GIS, regardless of size. They are drawn in vector mode as polygon features relative to the anatomical landmarks of the previously prepared templates (Fig 1). As defined by previous studies [13], [16], [18-20], identifiable fragments are fragments for which the element and side can be identified and precisely situated on the bone template. We would add to this definition that the outline of the drawn fragment is determined by the outline of the cortical surface of the fragment. This may seem irrelevant, but often fragments that lost part of their cortical surface but conserved medullary surfaces overlap with cortical surface from other fragments from the same bone element, and bias the results. Therefore drawing only the cortical surface circumvents any possible overlapping of fragments of the same bone. Fragments from the same bone element were drawn in a single layer. The radius and ulna were each drawn in a separate layer, in order to eliminate possible errors when calculating bone survivorship or spatial statistics, even though they are fused and generally considered as one element.

An attribute table storing data for every feature, added by the analyst, is linked to every layer. We recorded the reference number for each fragment and the three dimensions (length,

width, thickness) were measured for each specimen. Shaft fragments were differentiated by size (Table 2) and circumference classes (Table 3) according to Villa and Mahieu (1991) [38].

Table 2. Definition of categories separating shaft fragments by size according to Villa and Mahieu (1991) [38]

L1	Shaft fragments that are less than one-fourth the original length of the complete shaft
L2	Shaft fragment length is comprised between one-fourth and one-half of the complete shaft.
L3	Shaft fragment length is between one-half and three-fourths of the complete shaft
L4	Shaft fragment is more than three-fourths, essentially a complete or almost complete shaft.

Table 3. Definition of categories separating shaft fragments by circumference size according to Villa and Mahieu (1991) [38]

C1	Bone circumference is less than half of the original
C2	Bone circumference is more than half, but not a complete circumference, in at least a portion of the bone length
C3	Bone circumference is complete in at least one portion of the bone length

Drawing percussion marks

Separate point layers were created to illustrate all the identified percussion marks on the bone surface (Fig 1). We marked them with a point symbol which is also linked to an attribute table with information about the mark:

- n° bone element and n° fragment on which the percussion mark appears,
- Type of percussion mark (notch, pit, adhering flake and crushing),
- Percussion mark maximum length,
- Percussion mark maximum width,
- Percussion mark maximum thickness,
- Notch depth: three different categories: d1 (<½ initial cortical height), d2 (>½ and <1 initial cortical height) and d3 (=1, total cortical height),
- Notch form, three categories: fe1(= symmetric to the fracture, longest depth is in the centre part of the notch when the diaphysis is observed from a vertical angle); fe2(= asymmetric, longest depth of the notch is on the distal side) and fe3(= asymmetric, longest depth is on the proximal part),
- Text column for additional observations.

Points illustrating all the percussion marks are placed in the centre of the observed impact recording anatomical landmarks and the drawings of the fragments, e.g., points representing notches are situated in the middle of what is regarded as the fracture edge of the percussion mark. Points representing the rest of the percussion marks are situated in the centre of the observed impact area. We do not consider that the origin of the impact is at the centre of each percussion mark, but this choice was essential for standardizing the drawing process. We chose point features over line and polygon features to standardize and facilitate visualization and to fully exploit GIS spatial pattern analyses.

Bone survivorship

The GIS software can calculate the area defined by the outline of a polygon; therefore, we could calculate the area of each drawn fragment. With this information, we adapted the equation from Abe *et al.* [16] to calculate the frequency of cortical bone survivorship for each element:

Sum of fragments surface / whole bone surface *100 = preserved cortical bone surface %.

To illustrate cortical bone survivorship, we follow Marean's procedure for MNE calculations [13], to which we made modifications available with the more recent versions of ArcMap. Previous studies [13], [15], [18-20] mainly used grid (pixel) overlapping, which requires converting vector to raster files, making the process more time consuming. Our method, detailed in supplementary material, consists of directly overlaying polygons to calculate cortical bone survivorship.

Percussion mark frequency

The frequency of percussion marks was calculated in relation to the preserved area for each element of each series:

Number of percussion marks/preserved bone%*100= percussion mark %

This equation is an adaption of the Abe *et al.* [16] equation for calculating cut mark frequency. It was developed to improve frequency calculations by taking into consideration the fragmentation problem. Abe *et al.* [16] state that by dividing the number of cut marks by the preserved surface area, cut mark frequencies would closely match the original frequencies. Thus, "we can correct the number of cutmarks by the amount of examined surface area, much as demographers standardize population size by estimating population density". In the same way as Lyman [14], we

do not agree that this formula can be used to estimate the frequency of marks that have been destroyed, but we consider that it is a fair estimation of the frequency of preserved marks.

Patterns and clusters

When confronted with visual spatial data, we inherently organize, group, differentiate and transform these data into information. “Mapping” them like some previous studies [33-34] might result in a sense of the overall pattern of features and their associated values, but GIS spatial tools estimate concentrations of percussion marks by evaluating the interdistance between features. Calculating a statistic with GIS quantifies the pattern, which makes it easier to compare patterns and gain a better understanding of clusters. For this purpose, we used ArcGIS following spatial analyst and statistic tools:

Analysing patterns with Average Nearest Neighbour Distance (NND)

We used the Average NND tool to test for significant spatial clusters following Parkinson and colleagues’ method [18-20]. The tool calculates a nearest neighbour index based on the average distance from every point (percussion mark) to its nearest neighbouring feature. If the average distance between points is less than the average for a hypothetical random distribution, the distribution is considered to be clustered. If it is greater than one, the pattern is considered to be dispersed. The Z score represented by colour codes (S1 and S2 Tables) determines the value of probability that the observed pattern is significantly different from a random pattern [6]. The obtained values are sensitive to changes to the study area or changes to the Area parameter. The results are most appropriate when the study area is fixed. The defined area in which we tested for clusters is the bone surface calculated with the GIS polygon template. The NND was calculated for each view (anterior, posterior, medial and lateral) separately to accurately represent the surface area of the bone.

We used the NND tool to test for:

- Clusters taking into consideration all the percussion marks on a single bone element. We repeated this for the 10 bones in each series.
- Clusters taking into consideration one type of percussion mark (notch, pit and adhering flakes) for the whole series.

Visual representation of clusters/mapping clusters

To visually represent clusters, we followed Parkinson and colleagues’ method [18-20] for the Kernel density tool and implanted a new method using the Optimized Hot Spot Analysis tool. The Kernel Density tool counts the number of modifications in an area. This tool uses the quadratic

kernel formula described in Silverman [39] to fit a smoothly tapered surface to each point, which spreads out to a specified radius around the point. The highest cell value is at the point located in the centre of the spread, with the value tapering to zero at the boundary of the search radius distance. The sum of the intersecting spreads is then calculated for each cell in the output raster [6]. Kernel Density analysis is to some extent subjective as the analyst must input a search radius and cell size, which can significantly influence the results. The analysis can be carried out with only two points and still display a cluster zone.

On the other hand, Optimized Hot Spot analysis is more objective and uses the Getis-Ord G_i^* statistic to question the probability that a spatial distribution of values is random. To do this, the Optimized Hot Spot Analysis tool uses the average and median nearest neighbour calculations for aggregation and also to identify an appropriate scale of analysis. The tool computes each feature's average nearest neighbour distance and evaluates the distribution of all these distances. It defines high concentration zones (hot spots) and features that are more than a three-standard deviation distance away from their closest non coincident neighbour, considered as locational outliers (cold spots). The limit of this tool, and the reason why we chose Kernel density for some analyses, is that Hot Spot analysis requires a minimum of 30 points to perform calculations. The numbers of observed percussion marks in our assemblage are not sufficient for testing all of our hypotheses with this tool.

Estimated cluster zones with the NND tool for separate bone elements are represented with Kernel density, for which we used a fixed search radius (0.12) and cell size (between 1.1 and 3.2). Analyses were not performed for areas with three impacts or less. Optimized Hot Spot analysis was used to estimate and illustrate clusters of all the percussion marks combined from the ten bones in a series. We used Spearman's ρ to test for correlations between several values. The coefficients were calculated, and their statistical significance was tested using PAST software [40].

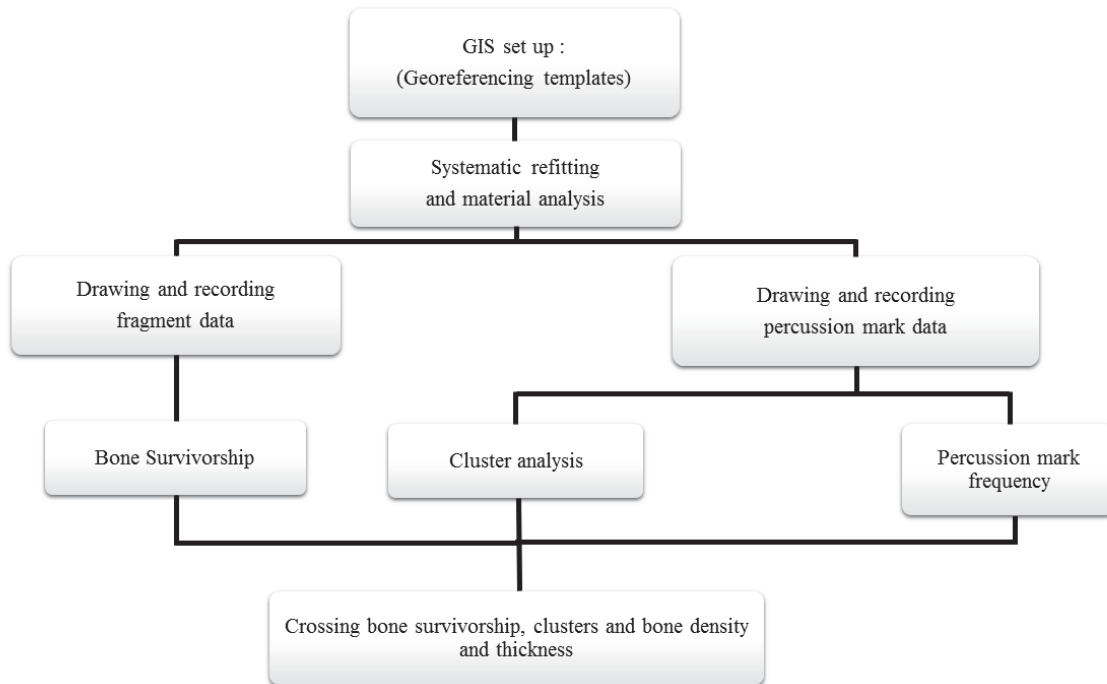


Fig 2. GIS stages for percussion mark analysis

Results

Experimental bone breakage remains

The breakage of the 40 cattle long bones resulted in 1 219 fragments, for which element and side were identified in 549 cases (44%) (Table 4). 701 fragments (56%) could not be identified, however, in terms of weight, the unidentified fragments represent only 1% of the total assemblage. The tibia series generated the highest rate of fragments (number of specimens produced: NSP), while the femur series produced the lowest, but these results are reversed in terms of number of identified and refitted specimens (NISP%). Among the NISP, 288 fragments (Table 4) bear at least one percussion mark, whereas among the unidentified fragments 71 have percussion marks. These latter are not included in our study.

The majority of NISP have a L1 and L2 length (Fig 3). Fragments with L1 length almost all have a C1 circumference, while the L2 fragments display more diverse circumferences. Percussion marks are most frequently identified on fragments with an L2 length and a C3 circumference (Fig 3). Spearman's test showed a positive correlation between the relative frequencies of shaft length and circumference for all identified specimens and the relative frequencies of percussion mark distribution of fragments bearing percussion marks (Humerus $\rho=0.09622$ $P=0$; Radius $\rho=0.85353$ $P=0.00041$, Femur $\rho=0.97268$ $P=0$ and Tibia $\rho=0$ $P=0.00488$).

Table 4 : Presentation of the studied faunal series and number of percussion marks.

<i>Bone Element</i>	<i>NISP^a</i>	<i>NISP %</i>	<i>NISP^b</i>	<i>NISP</i>	<i>IND^c</i>	<i>IND %</i>	<i>NISP</i>	<i>NISP</i>	<i>IND</i>	<i>IND</i>	<i>NISP</i>	<i>NISP</i>	<i>IND</i>	<i>IND</i>
<i>Humerus</i>	289	24%	108	37%	181	63%	66	81%	15	19%	11156	98%	179	2%
<i>Radius-ulna</i>	263	22%	119	45%	144	55%	61	79%	16	21%	8991	97%	108	3%
<i>Femur</i>	228	19%	130	51%	129	49%	68	80%	17	20%	18467	99%	98	1%
<i>Tibia</i>	439	36%	192	44%	247	56%	93	80%	23	20%	11207	98%	216	2%
<i>Total</i>	1219	100%	549	44%	701	56%	288	80%	71	20%	49821	99%	601	1%

^aNISP (number of specimens produced) = total number of fragments for each type of bone element, ^bNISP (Number of identified and refitted specimens), ^cIND (unidentified specimens), ^dPM (percussion marks)= number of percussion marks identified on each type of bone element.

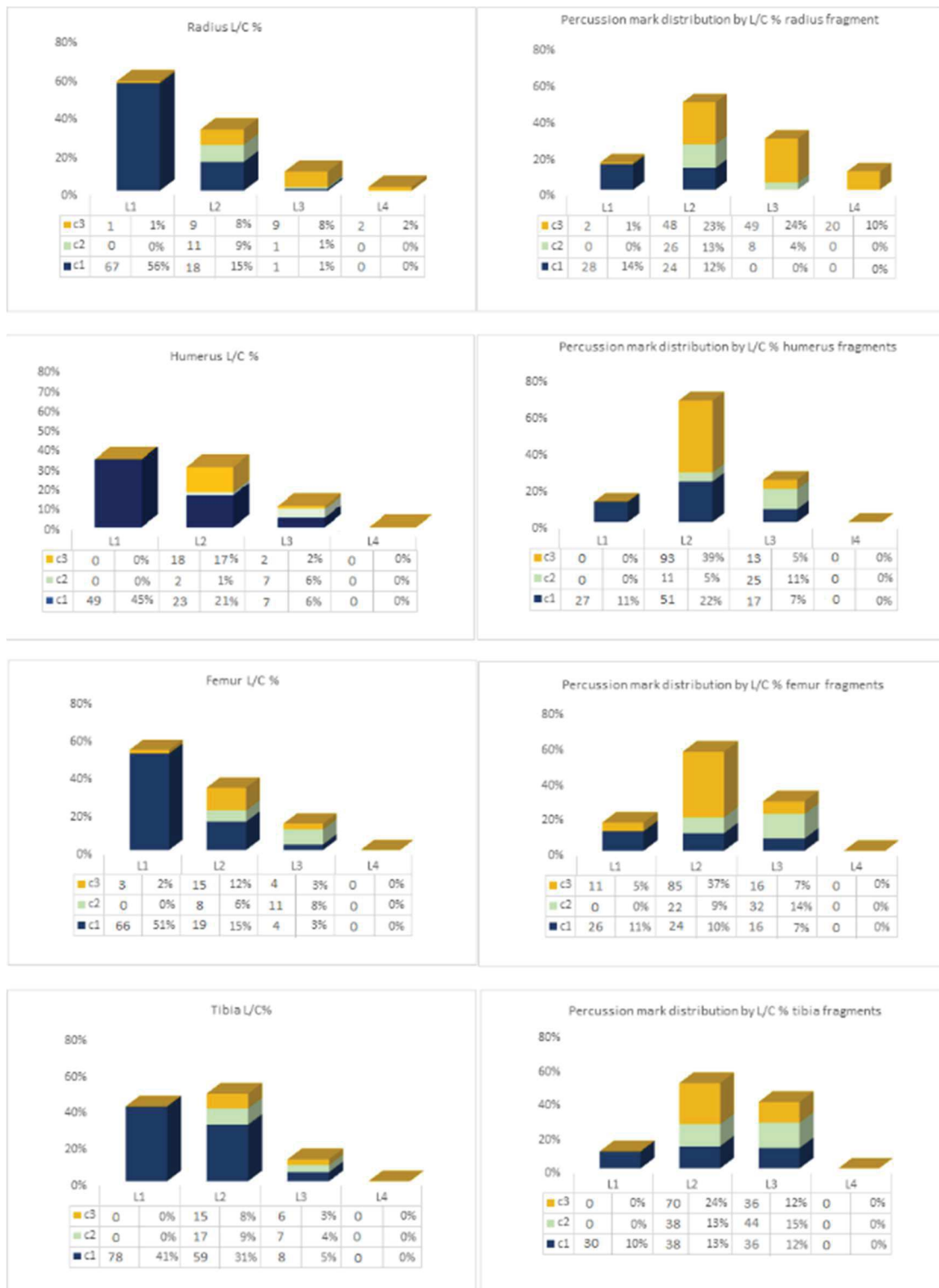


Fig 3. Distribution of NISP according to shaft length and circumference. Left column diagrams show relative frequencies of shaft length (L) and circumference (C) of all identified specimens; Right column diagrams show frequencies of percussion mark distribution according to relative frequencies of shaft length(L) and circumference (C) for specimens bearing percussion marks.

Bone survivorship

Results of cortical bone survivorship for each series of the four elements are represented in the form of a graduated colour map generated with GIS (Fig 4), accompanied by the rate of preservation (Tables 5-8). The maps represent composites of both left and right elements in the assemblage. The darker shaded areas indicate higher cortical survivorship. The results show that destruction resulting from percussion for marrow extraction affects exclusively the diaphysis of long bones, but the zones concerned and the extent of destruction vary for the different elements.

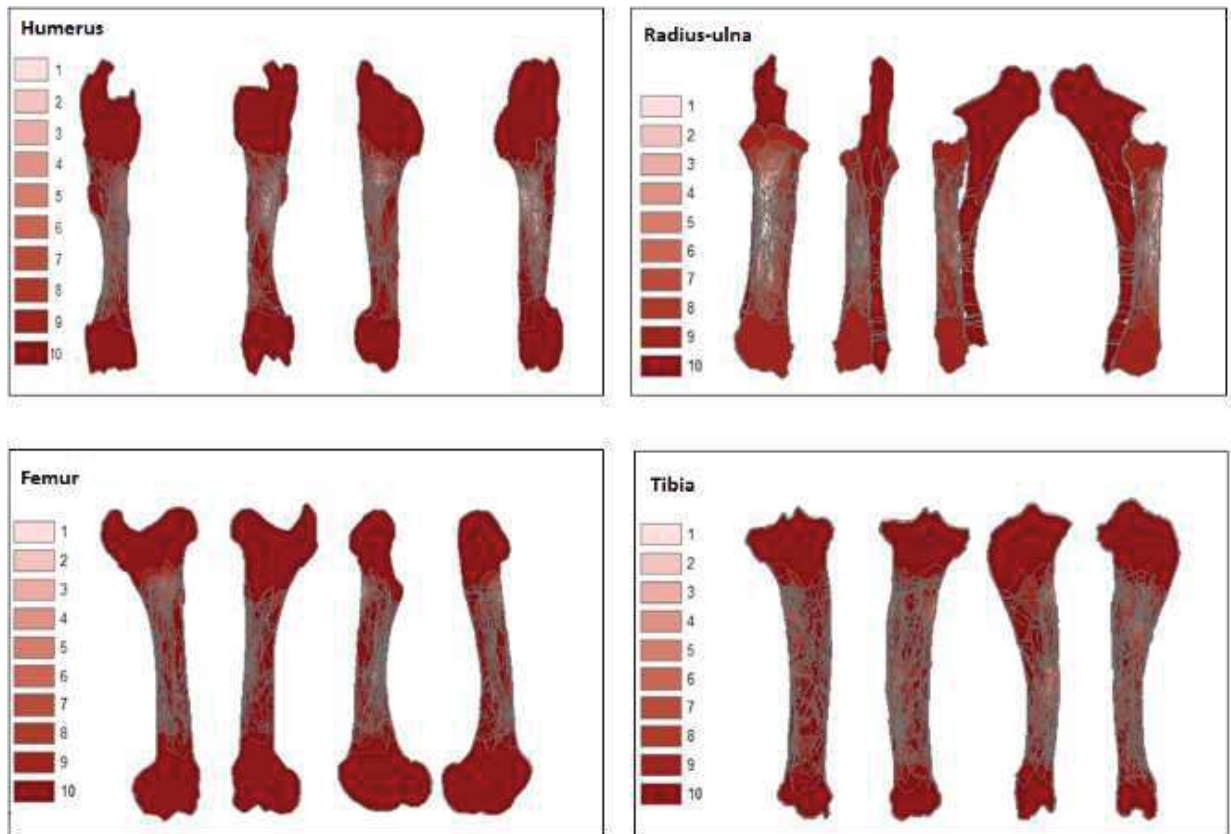


Fig 4. Bone survivorship composite of ten bone elements in a series for each bone element: humerus, radius-ulna, femur and tibia represented in each side in the following order: anterior, posterior, medial and lateral. Cortical preservation is indicated by shades of the colour red accompanied by a number from 1-10, darker shades and high numbers represent high cortical preservation.

Table 5: Series 1 Humerus.

Humerus ref. n°	Lateralisation	NI SP ^a	Cortical preservation % ^b	Total n° of blows ^c	Number of PM per side				Total n° of PM ^d	PM frequency ^e
					anterior	posterior	medial	lateral		
1-1	left	4	91%	110	2	1	4	11	18	20%
1-2	left	11	92%	78	3	0	7	10	20	22%
1-2	left	12	94%	93	0	8	9	2	19	20%
1-4	left	8	95%	38	0	2	8	9	19	20%
1-5	left	13	91%	40	3	4	4	12	23	25%
1-6	left	10	93%	50	13	4	9	4	30	32%
1-7	right	11	93%	51	11	1	3	3	18	19%
1-8	left	13	86%	50	4	3	8	11	26	30%
1-9	right	9	96%	32	8	4	7	4	23	24%
1-10	right	17	91%	30	9	15	15	2	41	45%
<i>Mean</i>		10.8	92%	57.2	5.3	4.2	7.4	6.8	23.7	26%
<i>Standard deviation</i>		3.4	2.8	27.2	4.6	4.4	3.4	4.1	7.2	8.1

^aNumber of identified specimens (NISP), ^bCortical preservation rate per element, ^cTotal number of blows inflicted per element, ^dTotal number of percussion marks (PM) per element and side, ^ePM frequency calculated according to cortical preservation.

Table 6: Series 2 Radius.

Radius ref. n°	Lateralisation	NI SP ^a	Cortical preservation % ^b	Total n° of blows ^c	Number of PM per side				Total n° of PM ^d	PM frequency ^e
					anterior	posterior	medial	lateral		
2-1	right	12	82%	115	12	3	6	4	23	30%
2-2	right	13	88%	88	18	8	0	3	28	33%
2-3	left	15	86%	48	8	12	0	0	19	23%
2-4	right	6	81%	94	10	3	0	3	14	20%
2-5	left	15	92%	29	16	2	0	0	17	20%
2-6	left	15	86%	108	13	11	0	5	27	34%
2-7	left	15	82%	131	14	9	0	3	25	32%
2-8	right	6	84%	71	6	4	1	6	16	20%
2-9	right	10	91%	67	17	4	0	2	22	25%
2-10	right	12	91%	53	9	6	0	1	15	17%
<i>Mean</i>		11.9	86%	80.4	12.3	6.2	0.7	2.7	20.6	25%
<i>Standard deviation</i>		3.5	4.1	32	4	3.6	1.9	2	5.2	6.3

^aNumber of identified specimens (NISP), ^bCortical preservation rate per element, ^cTotal number of blows inflicted per element, ^dTotal number of percussion marks (PM) per element and side, ^ePM frequency calculated according to cortical preservation.

Table 7: Series 3 Femur.

Femur ref. n°	Lateralisation	NI SP ^a	Cortical preservation % ^b	Total n° of blows ^c	Number of PM per side				Total n° of PM ^d	PM frequency ^e
					anterior	posterior	medial	lateral		
3-1	left	14	94%	83	11	2	4	5	21	23%
3-2	left	11	98%	56	3	5	6	1	14	15%
3-3	left	11	94%	87	8	1	9	12	29	32%
3-4	right	8	95%	41	13	2	2	10	26	18%
3-5	left	11	95%	55	10	3	7	11	30	33%
3-6	right	23	95%	30	11	2	13	1	26	28%
3-7	right	9	97%	50	11	3	2	2	17	19%
3-8	right	11	97%	12	1	4	12	6	22	24%
3-9	right	17	94%	49	16	6	4	8	33	36%
3-10	right	15	93%	37	8	5	0	2	14	16%
<i>Mean</i>		13	95%	50	9.2	3.3	5.9	5.8	23.2	24%
<i>Standard deviation</i>		4.4	1.6	22.6	4.5	1.6	4.3	4.3	6.7	7.5

^aNumber of identified specimens (NISP), ^bCortical preservation rate per element, ^cTotal number of blows inflicted per element, ^dTotal number of percussion marks (PM) per element and side, ^ePM frequency calculated according to cortical preservation.

Table 8: Series 4 Tibia.

Tibia ref. n°	Lateralisation	NI SP ^a	Cortical preservation % ^b	Total n° of blows ^c	Number of PM per side				Total n° of PM ^d	PM frequency ^e
					anterior	posterior	medial	lateral		
4-1	left	22	92%	16	6	7	9	4	26	28%
4-2	left	19	96%	13	1	8	3	6	18	19%
4-3	left	16	92%	27	7	15	0	4	26	28%
4-4	left	20	98%	15	3	8	5	10	26	26%
4-5	left	21	90%	26	7	8	2	6	23	25%
4-6	right	22	93%	26	21	16	6	4	47	50%
4-7	right	24	90%	28	22	3	5	2	32	35%
4-8	left	14	94%	26	4	6	7	6	23	24%
4-9	right	18	95%	21	11	12	6	6	35	37%
4-10	right	16	95%	21	14	13	4	5	36	38%
<i>Mean</i>		19.2	94%	21.9	9.6	9.6	4.7	5.3	29.2	31%
<i>Standard deviation</i>		3.2	2.6	5.5	7.2	4.2	2.6	2.1	8.4	9

^aNumber of identified specimens (NISP), ^bCortical preservation rate per element, ^cTotal number of blows inflicted per element, ^dTotal number of percussion marks (PM) per element and side, ^ePM frequency calculated according to cortical preservation.

Highest cortical survivorship was calculated for the ulna series with an average of 99%. This is due to the nearly absent medullar cavity and scarcity of bone marrow in the element. Due to this constant high preservation and the low number of observed percussion marks, the ulna series was excluded from further analysis. Average cortical preservation for the rest of the elements is as follows: hindlimb bones show a preservation rate of 95% for the femur and 94% for the tibia series. For the front limbs, the humerus series presents an average of 92%, while the radius series shows an average of 86%. The most recurrently affected zone for all elements is the proximal to central part of the diaphysis, but this is not systematic for all sides. For the humerus and tibia series, zones of low preservation are rare on the anterior side. The femur posterior side shows no zones with low preservation. The radius series shows zones of low cortical preservation on all four sides.

Patterns and cluster distributions

A total of 967 percussion marks were identified, comprising 237 in the humerus series, 206 in the radius, 232 in the femur and 292 in the tibia series. The most recurrent percussion marks in our sample are notches, pits and adhering flakes (Table 9). Fig 5 shows obvious concentration zones for some percussion marks, e.g., the proximal part of the femur's anterior side shows an important cluster of adhering flakes. However, it is more difficult to identify other marks that seem more dispersed or mixed up with others.

**Fig 5. Distribution of percussion marks along the long bone elements (humerus, radius-ulna, tibia and femur),
divided by type of percussion mark (each percussion mark is indicated with a specific symbol)**

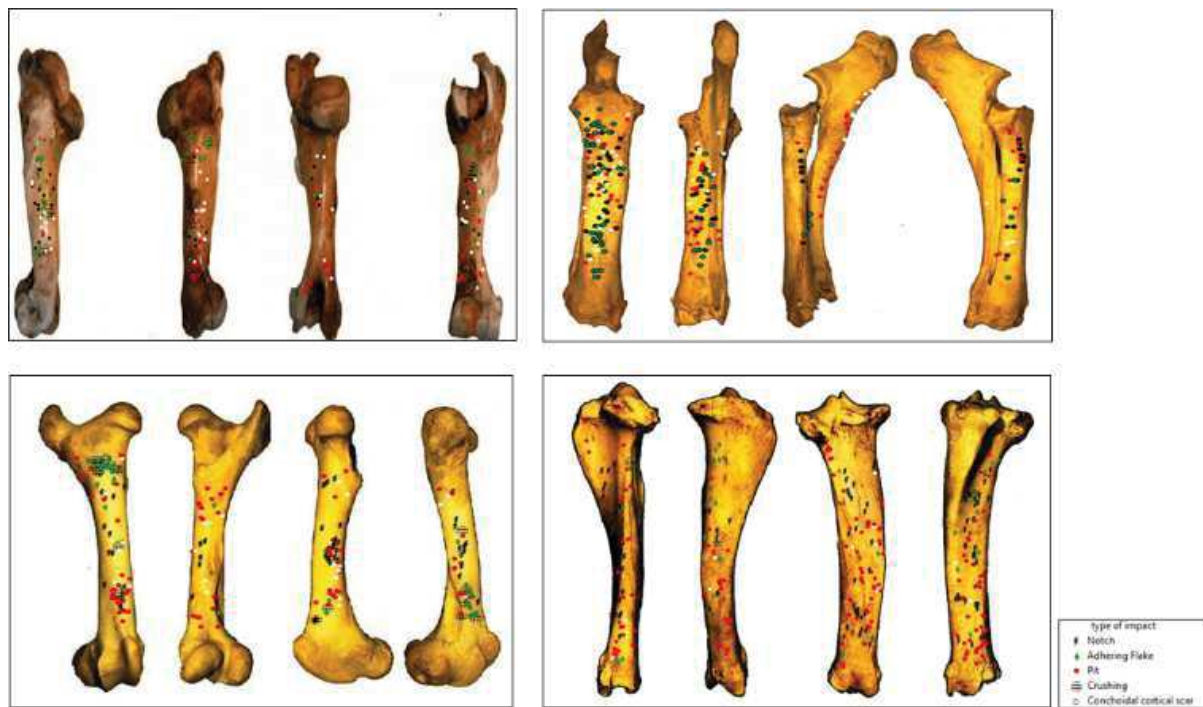


Table 9: Distribution of percussion marks by type of mark and element aspect.

Element aspect	Type of percussion mark	Humerus	Radius	Femur	Tibia	Total
Anterior	Notch	7 (13%)	32 (29%)	11 (12%)	34 (35%)	84 (24%)
	Pit	18 (34%)	16 (14%)	32 (35%)	45 (47%)	111 (31%)
	^a Adh. Flake	13 (25%)	39 (35%)	34 (37%)	14 (15%)	100 (28%)
	^b Crushing	4 (8%)	6 (5%)	8 (9%)	1 (1%)	19 (5%)
	^c C. c. scar	11 (21%)	19 (17%)	7 (8%)	2 (2%)	39 (11%)
Posterior	Notch	7 (17%)	17 (28%)	5 (15%)	31 (32%)	60 (26%)
	Pit	18 (43%)	18 (30%)	18 (55%)	51 (53%)	105 (45%)
	Adh. Flake	10 (24%)	14 (23%)	3 (9%)	9 (9%)	36 (16%)
	Crushing	0	6 (10%)	0	0	6 (3%)
	C. c. scar	7 (17%)	5 (8%)	7 (21%)	5 (5%)	24 (10%)
Medial	Notch	9 (12%)	5 (71%)	21 (36%)	10 (21%)	45 (24%)
	Pit	28 (38%)	1 (14%)	22 (37%)	19 (40%)	70 (37%)
	Adh. Flake	19 (26%)	1 (14%)	5 (8%)	14 (30%)	39 (21%)
	Crushing	3 (4%)	0	2 (3%)	1 (2%)	6 (3%)
	C. c. scar	15 (20%)	0	9 (15%)	3 (6%)	27 (14%)
Lateral	Notch	20 (29%)	11 (41%)	11 (23%)	18 (34%)	60 (31%)
	Pit	11 (16%)	9 (33%)	11 (23%)	25 (47%)	56 (29%)
	Adh. Flake	24 (35%)	4 (15%)	18 (38%)	6 (11%)	52 (27%)
	Crushing	3 (4%)	0	5 (10%)	2 (4%)	10 (5%)
	C. c. scar	10 (15%)	3 (11%)	3 (6%)	2 (4%)	18 (9%)

Abbreviations: ^aAdh. Flake = Adhering flakes; ^bCrush =Crushing mark and ^cC.C. scar = Cortical conchoidal scar

We compared the number of inflicted blows and percussion mark frequency to see if there is a correlation between the two values (Tables 5-8). None of the elements showed statistically significant correlation for the two variables (Humerus $\rho=0.56618$ and $P=0.08797$; Radius-Ulna $\rho=0.61968$, $P=0.05602$; Femur $\rho=0.06667$ $P=0.85481$ and Tibia $\rho=0.29632$ $P=0.40578$).

We also wanted to determine whether the experimenter found a more effective technique for breaking the bone over time and after several bone element breakages. For this, we ran a Spearman's correlation test between the total number of inflicted blows and the number of experimental attempts (from 1 to 10) (Tables 5-8) (Fig 6). Results showed a significant negative correlation for the humerus ($\rho= -0.77204$ and $P=0.00888$) and femur ($\rho=-0.72121$ and $P=0.01857$), which means that the number of blows required to breach the cavity and fully extract the marrow tends to decrease from the first attempt to the last. Non-significant correlation was found for the radius ($\rho = -0.22424$ and $P = 0.5334$) and tibia series ($\rho =0.32004$ and $P=0.36732$).

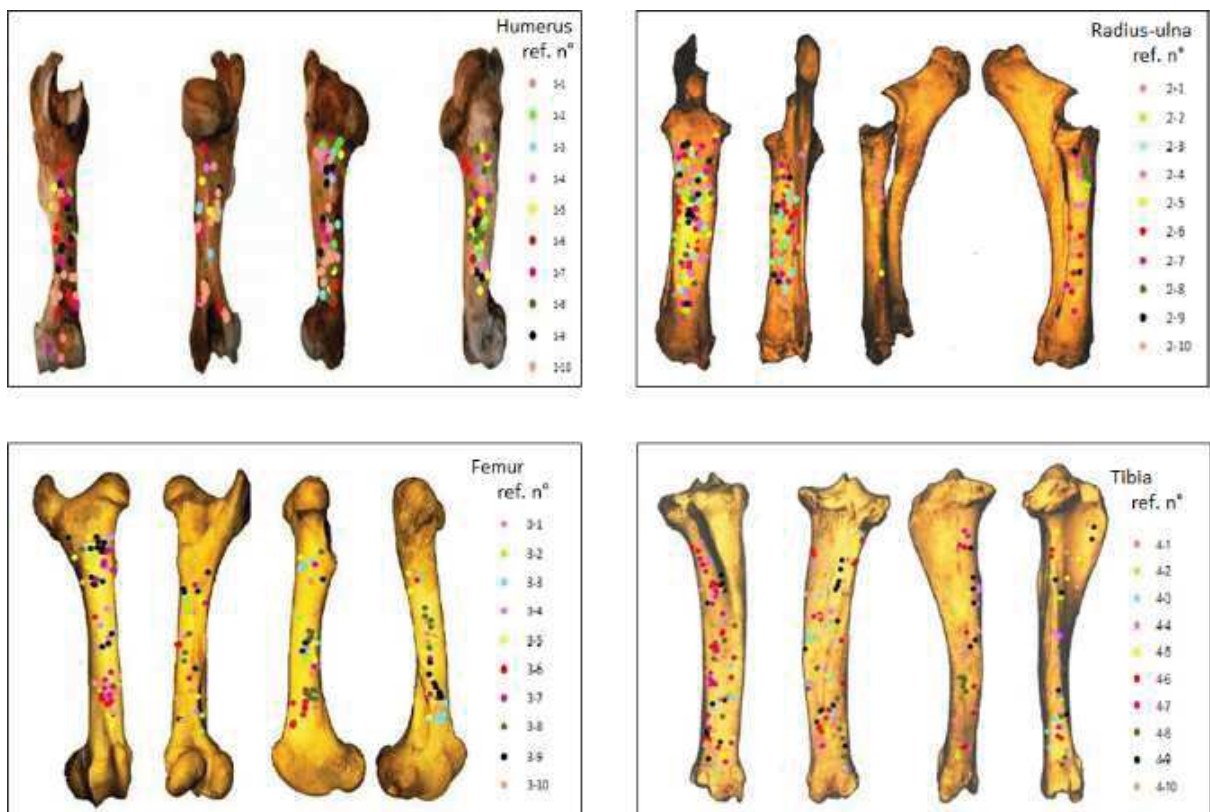


Fig 6. Distribution of percussion marks along the long bone elements, with different colours representing the marks made by different experimental attempts

Testing for clusters per element

Using the GIS average NND tool we determined the existence of cluster zones per side on each bone element (S1 Table). Results show percussion mark clusters on 37 out of 40 long bone

elements. Only one radius element (ref n° 2-9) and two tibia elements (ref. n° 4-2 and 4-5) showed no significant clusters.

To illustrate the identified cluster zones, we used the kernel density tool (Figs 7-10), which shows significant variation in the distribution of these clusters across the different elements. The distribution of number of clusters by side (Anterior, Posterior, Medial and Lateral) and portion of the shaft (Proximal, Central, Distal) is calculated and summarized in Fig 11.

In the humerus series, clusters are most recurrent on the lateral and medial sides (Fig 7), (S1 Table). The most impacted zones on the lateral side are the central and distal parts of the diaphysis, and the proximal and distal parts of the diaphysis on the medial side. The identified clusters on the posterior and anterior sides are randomly distributed on the diaphysis (Fig 11). The radius series clusters are most frequently identified on the anterior side of the diaphysis (Fig 8), (S1 Table), with the highest rate on the central part (Fig 11). Posterior side clusters are less recurrent, but are consistent on the proximal and central parts of the diaphysis. The lateral and medial sides rarely show cluster zones, but the few representative zones are situated on the proximal part of the diaphysis. Femur clusters are most recurrent on the anterior and medial sides (Fig 9), (S1 Table). The anterior side clusters are located on the proximal and distal parts of the diaphysis, and the medial side clusters on the central and distal parts. Clusters on the posterior and lateral sides are less frequent and equally distributed on the shaft. Like the radius series, tibia clusters are most recurrent on the anterior and posterior sides, although with a lower rate. No single portion of the diaphysis can be differentiated (Fig 11).

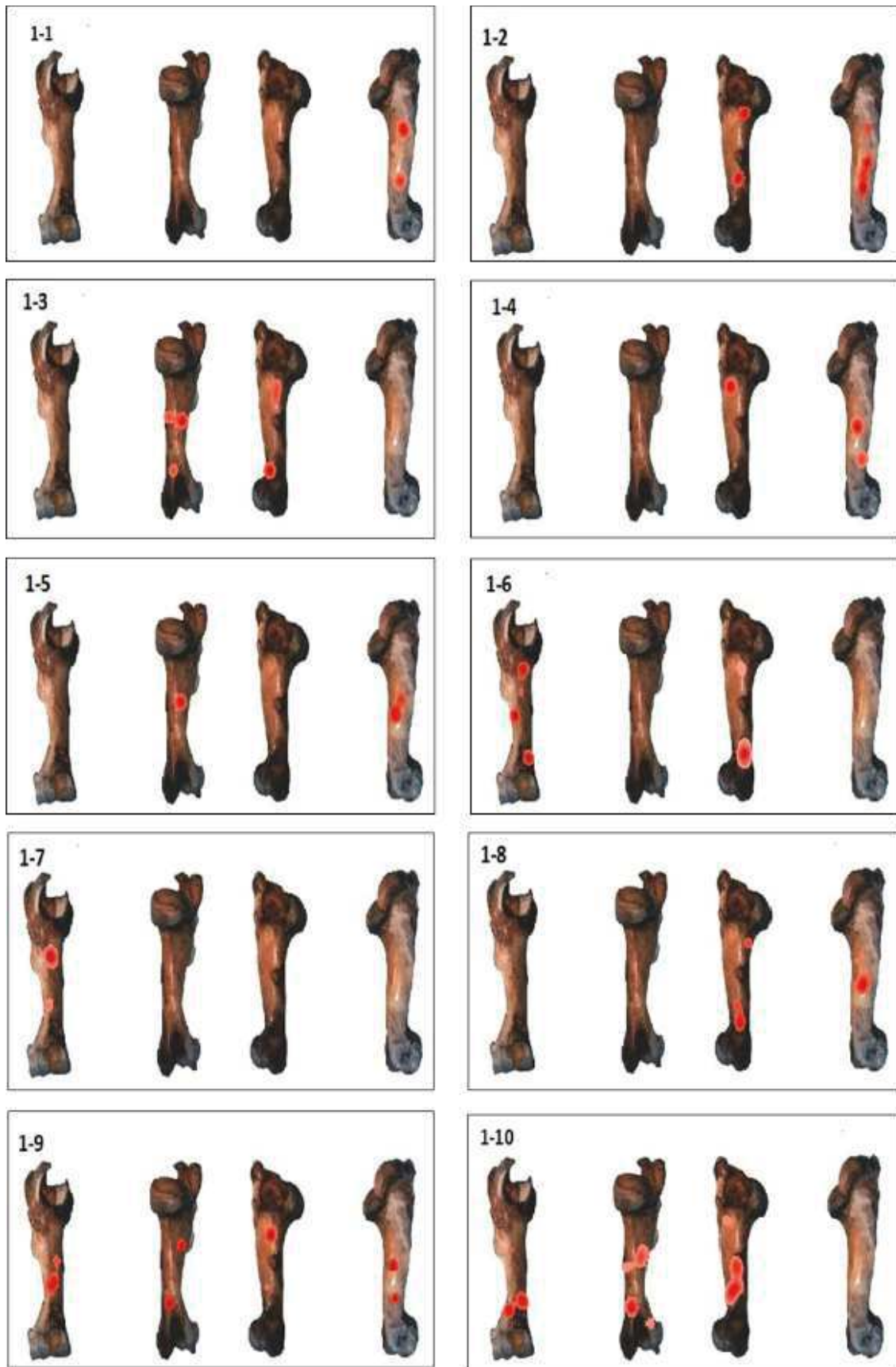


Fig 7. GIS Kernel density analysis results of percussion mark distribution on the four aspects for each humerus. Dark red areas indicate the highest concentrations of percussion marks.

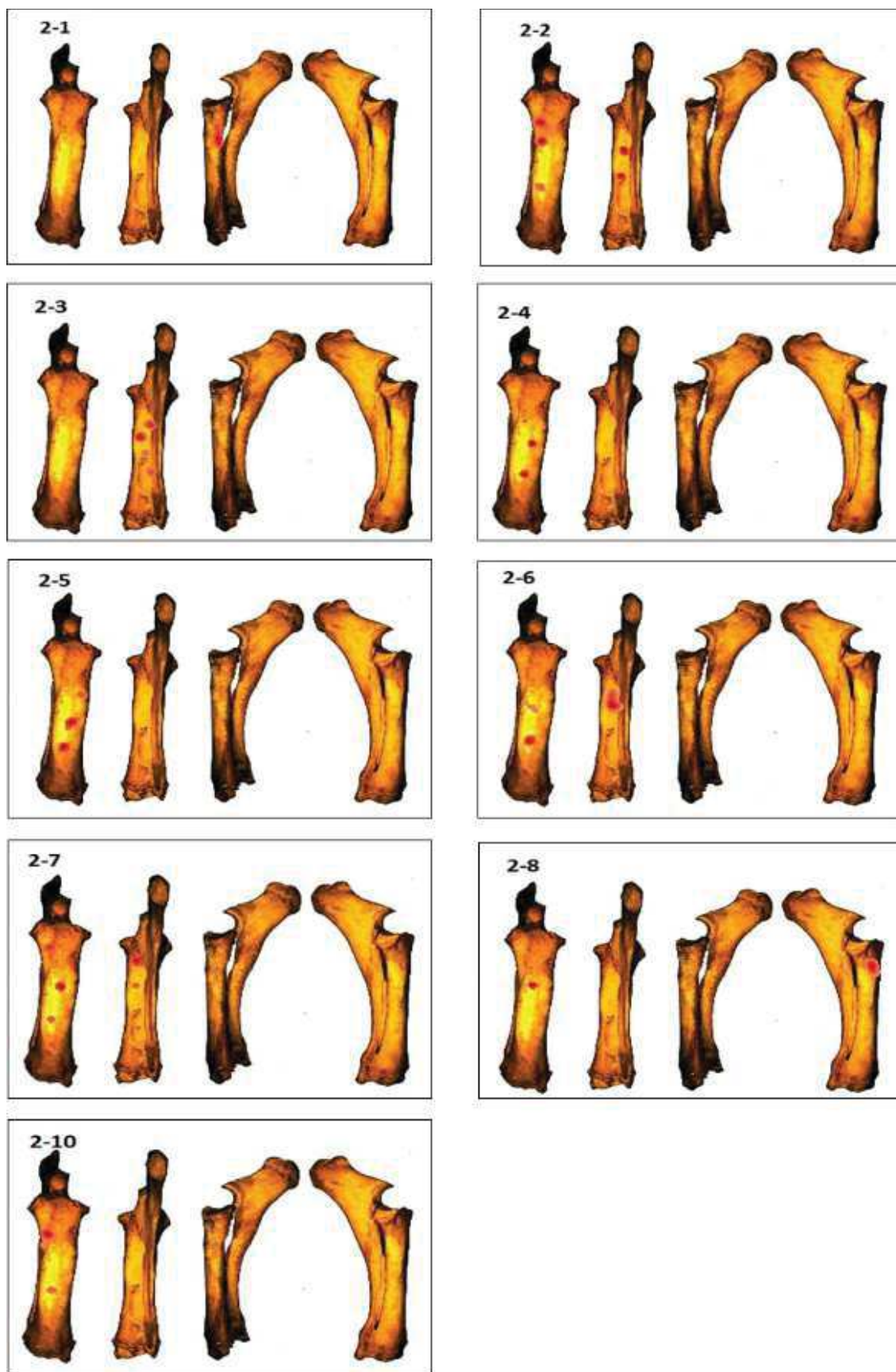


Fig 8. GIS Kernel density analysis results of percussion mark distribution on the four aspects for each radius.

Dark red areas indicate the highest concentrations of percussion marks.

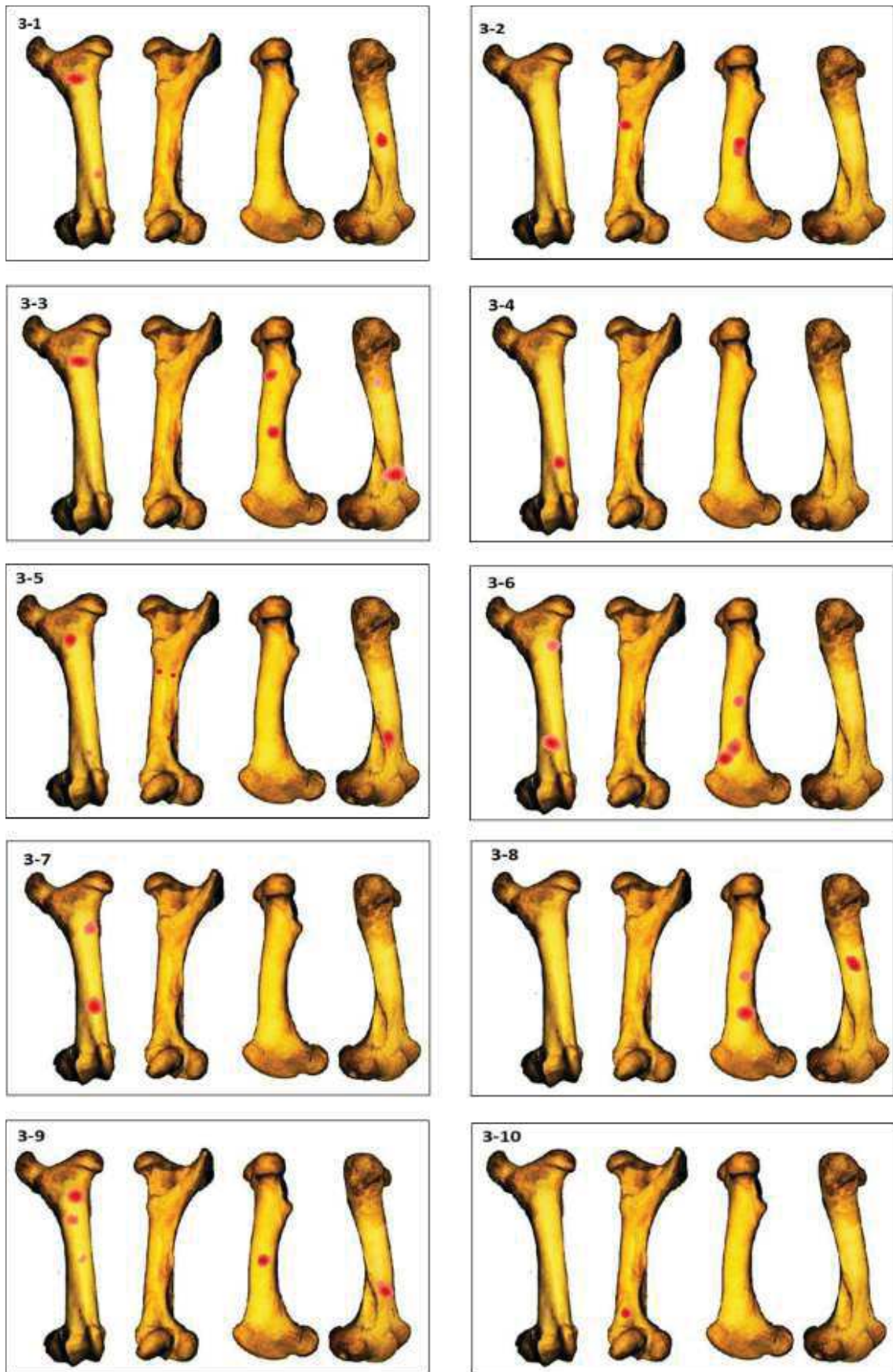


Fig 9. GIS Kernel density analysis results of percussion mark distribution on the four aspects for each femur.

Dark red areas indicate the highest concentrations of percussion marks.

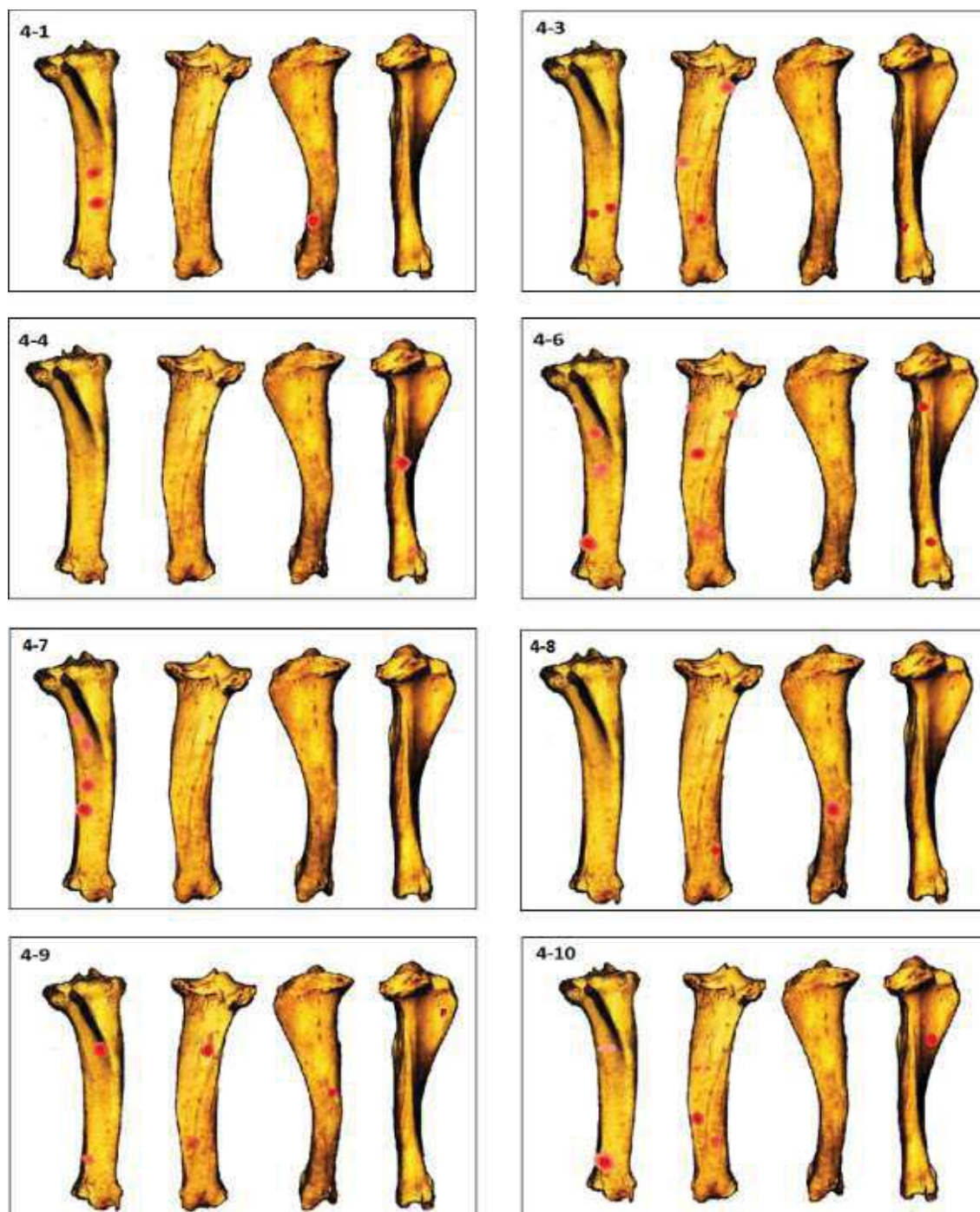


Fig 10. GIS Kernel density analysis results of percussion mark distribution on the four aspects for each tibia.

Dark red areas indicate the highest concentrations of percussion marks.

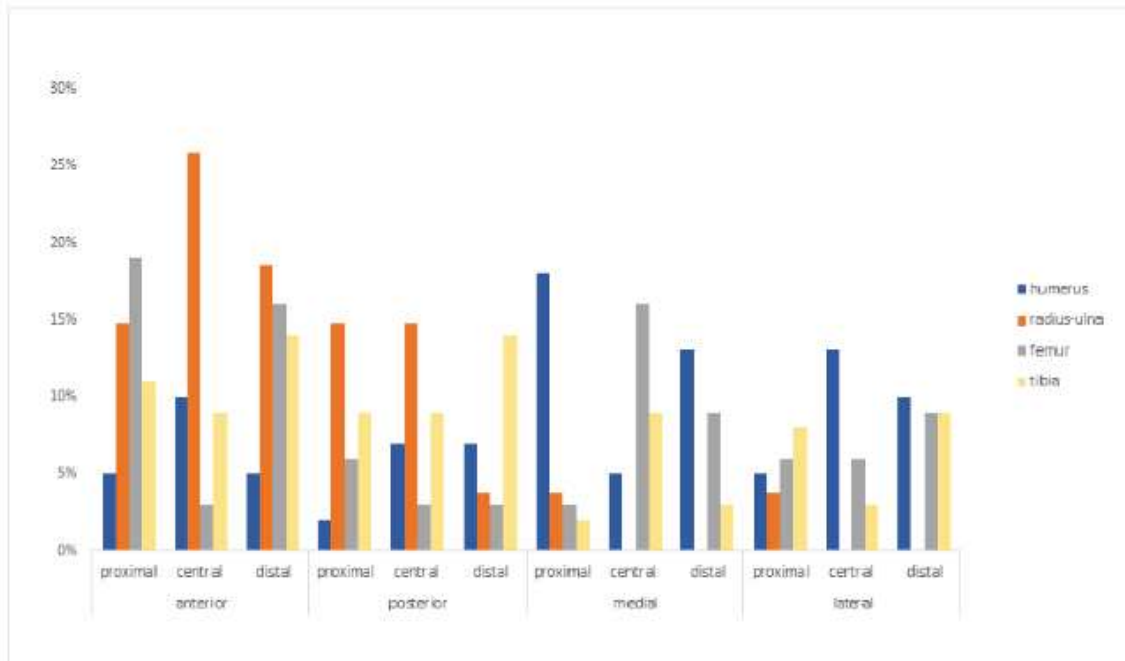


Fig 11. Summary of Kernel density cluster distribution according to side and shaft portion.

Cluster patterns were identified for all the 10 bones of each series combined using Optimized hot spot analysis (Fig 12). The results represent a synthesis of the individual Kernel density map elements and reveal results corresponding to Fig 11. The advantage of Hot spot analysis is that it balances out the degree of clustering by taking into consideration the different views for the analysis.

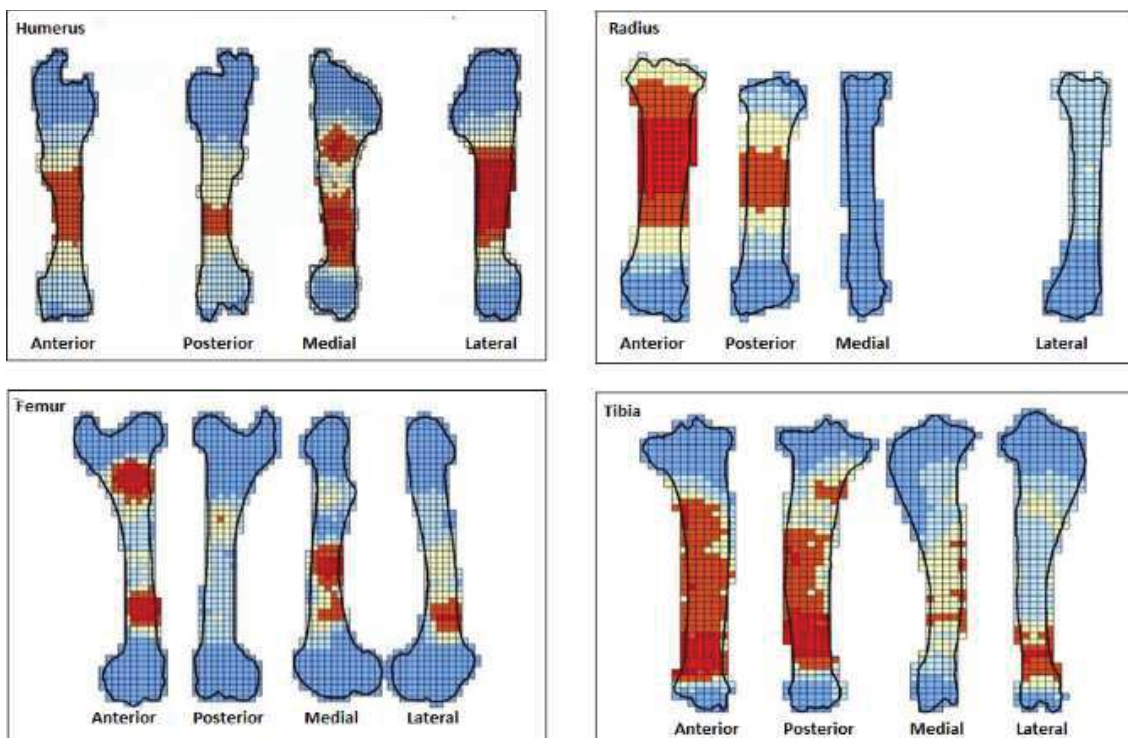


Fig 12. Optimized Hot spot analysis of combined percussion marks from the ten bone elements in each series.

In sum, the proximal and distal parts of the humerus diaphysis are cold spots, except for the medial side. The whole humerus diaphysis represents a hot spot zone for the lateral side. Anterior and posterior side hot spot zones display lower confidence levels of clustering (Fig 12) and correspond to the central to distal parts of the diaphysis.

The combined radius series percussion mark cluster analysis defines a high confidence hot spot zone on the anterior side of the diaphysis. The posterior side shows a well-defined hot spot zone on the proximal and central shaft. The lateral medial sides are identified as cold spots.

For the femur series, the well-defined hot spot zones are located on the anterior, proximal and distal parts of the diaphysis. Other significant hot spots are located on the medial central to distal part of the shaft and the distal part of the lateral shaft.

The most impacted sides for the tibia series are the anterior and posterior sides. However, the whole diaphysis is affected and the most impacted zone is the distal part of the shaft. The same zone is impacted for the lateral side as well.

Testing for clusters per type of percussion mark:

The three most recurrently identified percussion marks for the whole sample (notches, pits and adhering flakes) were tested using the NND tool (S2 Table) for clusters separately. Kernel density results show that while the overall patterns were quite distinct between the elements when all percussion marks were considered (Fig 12), similarities appear when we consider a single type of percussion mark. Notch clusters are more variable but frequently appear in the central part of the shaft (Fig 13). Pit clusters, with the exception of the radius series, are most recurrent on the distal part of the shaft (Fig 14). Adhering flake clusters are most recurrent in the proximal and distal parts of the shaft for all elements (Fig 15).

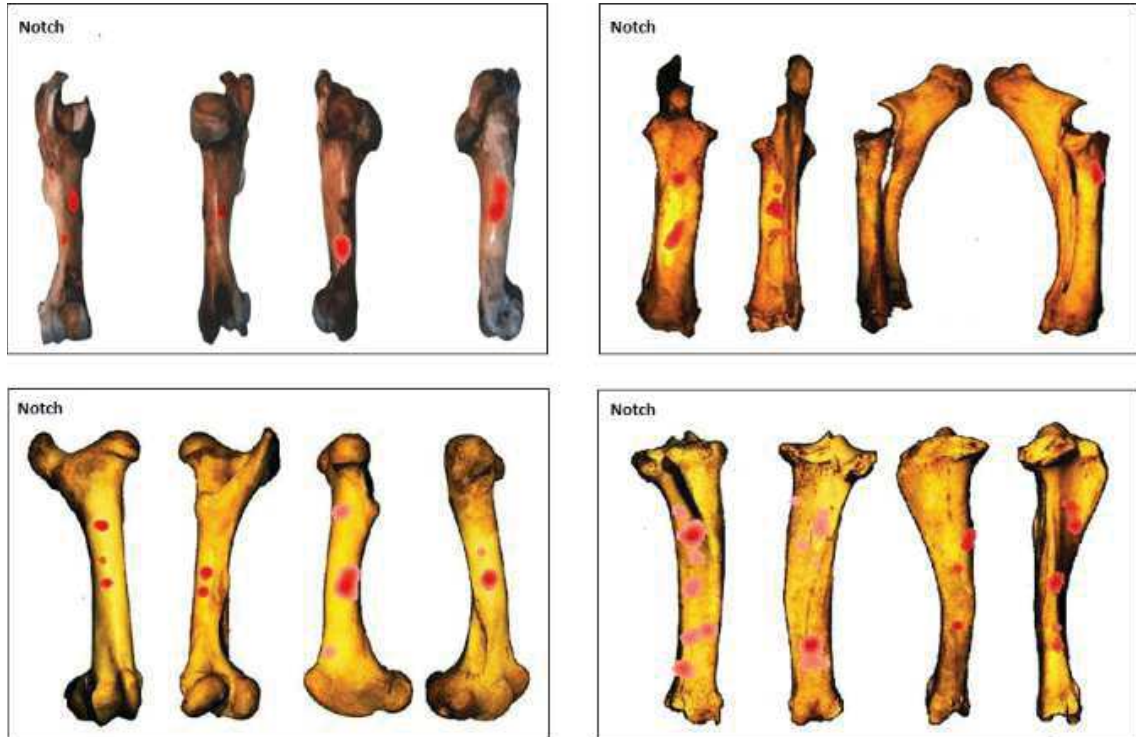


Fig 13. GIS Kernel density analysis results for notch distribution on the four aspects for each bone element series. Dark red areas indicate highest concentrations of notches.

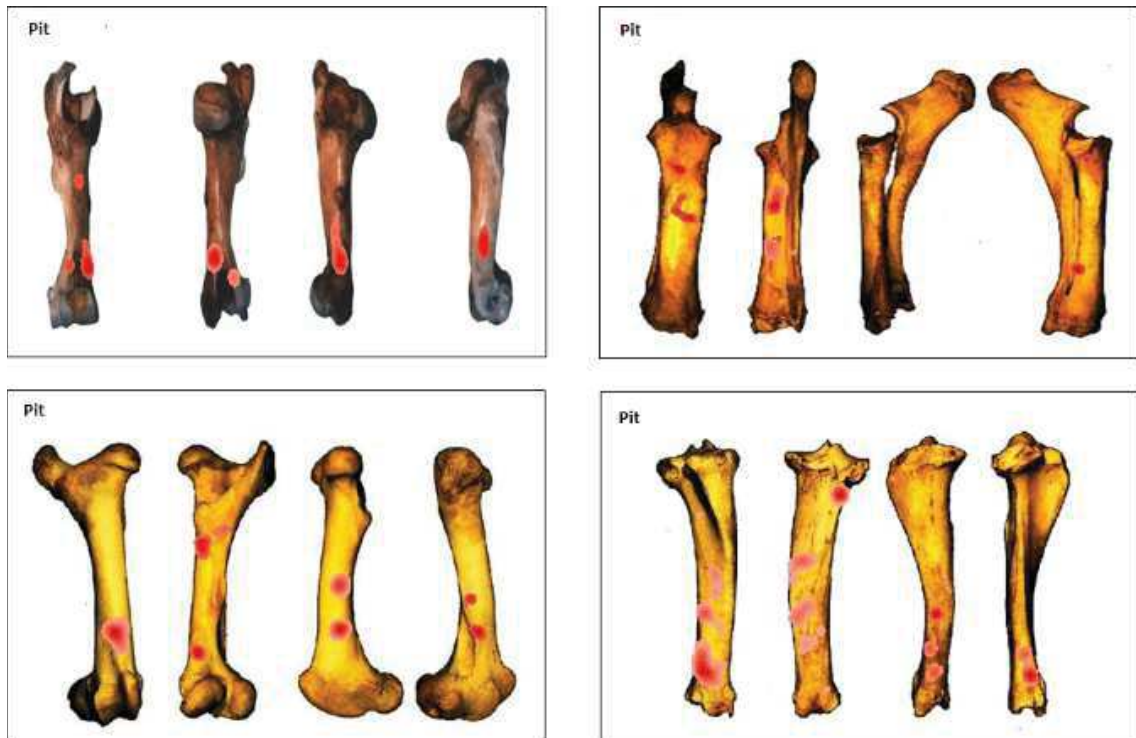


Fig 14. GIS Kernel density analysis results of pit distribution on the four aspects for each bone element series. Dark red areas indicate highest concentrations of pits.

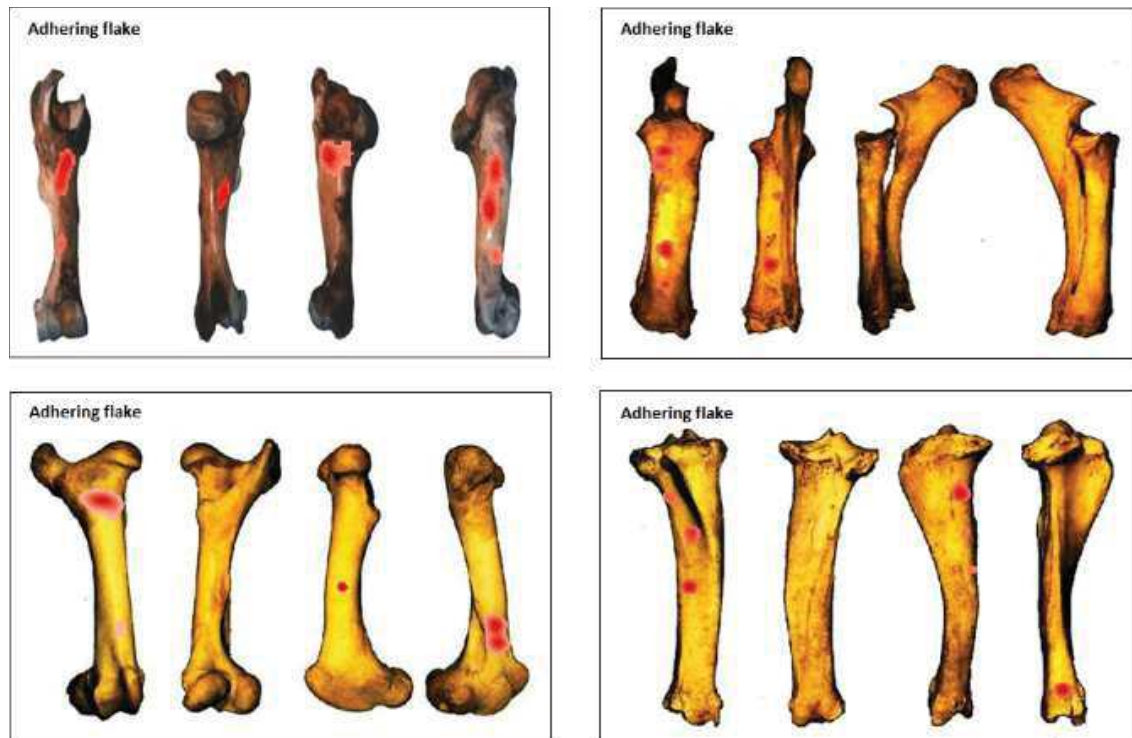


Fig 15. GIS Kernel density analysis results for adhering flake distribution on the four aspects for each bone element series. Dark red areas indicate highest concentrations of adhering flakes.

Discussion

Standardizing the documentation process

GIS software can be adapted and can provide valuable insights for non-geographical data, but it is important to clarify that this application has certain limitations. For the time being, georeferenced and uniformized templates constitute an appropriate option for establishing a workspace in GIS. However, this adjustment deforms all metric measurements, and therefore the drawings made using the software are not an exact replication. To adjust these values, most of the calculations can be expressed in frequency rates. Considering this, we underline the need for standardization and clear protocols for recording spatial data, i.e., precise criteria to define the placement of points (percussion marks) or outlines of polygons (fragments). If this is carried out correctly, the ArcGIS database can be used to organize and analyse big data and provide venues to explore a variety of questions in a short amount of time. For this study, we precisely calculated the examined surface and evaluated concentrations of percussion marks based on their spatial interdistances and not on imposed predefined portions. The principal advantage of GIS is the visual representation of the results. “Bone maps” of survivorship and clusters capture and convey information in a particularly insightful manner for the purpose of this study. This becomes clear when we compare figures with simply mapped features (Figs 5 and 6) to mapped clusters (Figs 7-12).

Fragmentation and bone survivorship

Bone survivorship analysis evaluates bone loss, which is usually neglected in experiments. Here, all the fragments were directly identified as belonging to each element during the experiment and were collected, and in theory we should have approximately 100% bone survivorship, but this is not the case, due to several factors, referred to as laboratory taphonomy by Costamagno [41] and Bartram and Marean [42]. Costamagno discusses loss due to sampling procedures and analytical methods. In our case, part of the loss is, as mentioned before, due to the exclusive selection of the fragment's cortical preserved surface. The range of fragment material loss is 5-14%. The weight of undetermined fragments does not exceed 3% in any element series and does not explain the low 86 % average survivorship for the radius series. Other loss derives from putting the material through the different phases, starting from the experiment to the final step of the analysis. During breakage of the bone, one percent is lost immediately due to the crushing effect and the parting distance of small-sized fragments from the experiment spot. During the cleaning process, a certain number of fragments are lost or mixed up because of the large quantity of experimental material (400 bones), and cannot be reattributed to bones. The GIS method for bone survivorship proved to be effective because we not only calculate the percentage of the examined surface, but we can also visualize it and cross this data with percussion patterns and bone mineral properties. Crossing bone survivorship with clusters and patterns proved to be a better solution than the frequently used graphic representation of the relationship between the total recovered bone portions and bone portions with percussion marks. Indeed, it provides a visual representation of both and can reveal possible connections.

For calculating the fragmentation of our sample, we follow Marshall and Pilgram's model of fragmentation effect [43]. As fragmentation intensity increases, the NISP decreases because fragments become so small as to be unidentifiable. The highest fragmentation rates in this sample were estimated for the tibia and humerus series, which showed high NSP but lower NISP rates (Table 4). However, this has no impact on cortical preservation, i.e., the examined surface did not decrease in size.

Pickering and Egeland's hammerstone percussion experiment on deer humeri and radii elements, which also involved fracturing bones to a sufficient extent for complete marrow extraction, reports significantly higher fragmentation for the radii elements [28]. Moclan and Dominguez-Rodrigo [34] report similar results although the difference in fragmentation from their sample is less significant. Pickering and Egeland attribute this difference to the higher number of blows impacted on the radii to expose the medullary cavity (mean per individual radius=6, humerus=2). On the contrary, in our sample, the tibia series has the lowest number of impacted

blows (mean per series=21). In our experiment, the highest number of impacted blows was recorded for the radius series (mean per series: radius=83), but this did not result in higher fragmentation, although it did result in the loss of 14% of the examinable surface, as shown by the bone survivorship results.

This difference can be explained by the variance in the concepts of the two experiments. The significant difference in the number of inflicted blows in these two experiments for the same bone element is due to the use of bones from different species. Indeed, deer bone elements are more gracile than cattle bones, and contrary to Pickering and Egeland's experiment, volunteers in this study are novices or unexperienced in hammerstone percussion. Moreover, graduated bone survivorship "maps" (Figs 4-7) demonstrate that there is no constant fracture pattern. The numerous fragment outlines intersect, but rarely overlap, demonstrating multiple variable fracturing outcomes for the same bone element, even with standardization and systematization.

Percussion mark clusters

Percussion marks were analysed per type of mark and per element with the NND and represented with the Kernel Density tool. The drawback with these tools is that illustrations and analyses are performed on a four-sided image of a bone element, which ignores the 3D shape of the bone. NND and Kernel density calculations are limited to one aspect of an element at a time, meaning that no connections can be made between the different aspects of the element (anterior, posterior, medial and lateral). This can be overcome with Optimized Hot Spot analysis. However, this tool requires a minimum of 30 features to conduct the analysis.

Cluster zones were examined in order to assess the degree of preservation of elements. Bone survivorship results show that zones with low cortical preservation (Figs 4-7) correspond well to clusters (hot spots) (Fig 12). Percussion marks themselves are read as negatives on the bone surface, i.e., zones that damage the cortical surface of the bone. In addition, when the experimenter inflicts additional blows to completely breach the shaft on a zone already bearing percussion marks, he/she obliterates them by crushing or reducing the size of the fragments to such an extent that they are no longer identifiable. In sum, the process of bone breakage itself reduces our ability to completely grasp marrow extraction by examining the material. Hence, during bone marrow extraction by humans, before sedimentary processes start acting, the most impacted zones by percussion are the least preserved zones, even in controlled conditions.

Abe et al. [16] state that "fragmentation generally decreases the number of cut marked fragments and cut mark counts relative to total fragments" (Abe et al. 2002:649 Abe et al. (2002:657) and that a "key assumption that all zooarchaeologists make is that more intensive

cutting (more cutting actions) results in higher frequencies of cutmarks on the bone surface.” This is generally assumed for percussion marks as well. However, experiments by Egeland [44] found that there is a statistically significant negative correlation between the number of hammerstone blows and percussion mark frequency ($r=-0.234$, $P=0.045$). In our sample, none of the elements showed statistically significant correlations for the two variables (Humerus $\rho = 0.56618$ and $P = 0.08797$; Radius-Ulna $\rho = 0.61968$ and $P = 0.05602$; Femur $\rho = 0.06667$ and $P = 0.85481$, Tibia $\rho=0.29632$ $P=0.40578$). We suspect that this is because the number of blows inflicted in Egeland is very low as experimenters had previous knowledge of hammerstone percussion. Several authors have underlined that professional butchers [14-30] or people practicing marrow extraction leave fewer traces on bone surfaces as their goal is to finish the task with the least possible effort. A person experimented in marrow extraction would be more efficient and would break the bone with fewer blows than a novice.

Intuitive fracturing

We compared cortical bone survivorship and cluster analysis with Lyman’s density data [45] and Barba and Dominguez’s cortical thickness [46] data to evaluate whether the least preserved and most impacted surfaces can be correlated with fragile spots on the bone. GIS graduated maps of density and thickness measurements (S3 Fig) resulted in similar divisions and Spearman’s test showed a positive correlation for both values. Results showed that the least dense and least thick parts of the bone do not particularly correspond to low cortical preservation or cluster zones. The choice of impact points was not influenced by the bone’s mineral properties but possibly by the bones physical, morphological and physiological characteristics. These factors could result in unintentional patterns on the bone that may not be entirely guided by the individual’s intention but rather by the animal’s anatomy. For instance, the medial side of the humerus is flatter than the other sides, and thus more easily stabilized on the anvil. The video recording of the experiment showed that during the first blows to each humerus element, the volunteer recurrently put the medial side on the anvil and impacted the lateral side. In the final impacts, the individual flips the bone and impacts the medial side to completely break the shaft. That is why we see preferential sides when all percussion marks are combined (Fig 12). When we take into consideration a single type of percussion mark, the bone element’s morphology can also explain why preferential portions of the shaft were impacted. Notch clusters are most recurrent in the central portion of the shaft (Fig 13), where the hammerstone can strike the bone easily without slipping from the bone surface. Pit clusters appear on the distal part of the shaft (Fig 14), where the curved surface and epiphyses present obstacles for hammerstone impact. At this stage of the analysis, we cannot confirm or refute these statements, as every series was broken by a

single individual. The analysis of the rest of the experimental material will help to check morphological conditioning factors.

Conclusions

Through the study of this experimental sample, we observed the effectiveness of the GIS-based method and drew some conclusions relative to intuitive bone fracturing.

Bone morphology plays an important role in experimental bone breakage by beginners. Adaptation to the shape of the bone results in repetitive gestures and percussion mark pattern. These patterns are not perfectly standardized, but they show cluster zones of percussion marks for each bone element. Bone survivorship and a visual presentation of the examined surface show important links. Results in controlled experimental conditions show that the most impacted zones were the least preserved, and bone loss in the same zones would be much higher after the actions of taphonomic agents. Therefore, in archaeological assemblages, the connection between the examined surface and the pattern needs to be examined and clarified before making conclusions on the concentration and patterns of marks.

This study shows the potential of GIS spatial statistical abilities to improve existing quantifying methods and visually presenting the obtained results. The software provides a convenient system for stocking and analysing large data assemblages while considering the spatial link for input information. Analyses of modern experimental bone assemblages using the GIS method can provide valuable and easily shared analogues with which to compare percussion mark distributions in archaeological assemblages.

This study can also be used as a complementary experiment to Parkinson's studies [18-20] and assist in the determination of bone agent modifiers and their order of access, by adding hominid-induced marks to the large canid and felid database. It also underlines the importance of crossing bone survivorship with mark distribution, especially for archaeological assemblages, where taphonomic agents would considerably decrease the observable cortical surface. Crossing the two in a visual manner can relativize and provide information on the extent of fragmentation effects on percussion mark frequency.

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Supporting information

S1 Table GIS Cluster Analysis for percussion marks for the four bone elements (Humerus, Radius, Femur and Tibia) using Average Nearest Neighbour. Analysis was performed on the four aspects of the elements. The distance between each percussion mark and its nearest neighbour was measured. The nearest neighbour index (NNI) is the observed distance divided by the average expected distance in a hypothetical random distribution. If the NNI is less than 1, the pattern is considered clustered. If the NNI is greater than 1, the trend is towards dispersion. Colour codes (Z score) indicate the degree of clustering or dispersion. Null values signify that the number of counted marks was 3 or less.

S2 Table GIS Cluster Analysis for individual type of percussion marks for the four bone elements (Humerus, Radius, Femur and Tibia) using Average Nearest Neighbour. Analysis was performed on the four aspects of the elements. The distance between each percussion mark and its nearest neighbour was measured. The nearest neighbour index (NNI) is the observed distance divided by the average expected distance in a hypothetical random distribution. If the NNI is less than 1, the pattern is considered clustered. If the NNI is greater than 1, the trend is towards dispersion. Colour codes (Z score) indicate the degree of clustering or dispersion. Null values signify that the number of counted marks was 3 or less.

S1 Fig. Graduated maps of thickness measurements according to Barba et al (2005). Darker blue zones represent the thicker portions of the bone.

S1 Protocol GIS percussion pattern analysis method

Author Contributions

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Writing – original draft: T. Stavrova.

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III. 5. Comment fracturer un os long ? Le poids de l'intuitivité

Publication n°3: *Journal of Archaeological Method and Theory*, in prep. (soumission 2019)

A way to break bones? The weight of intuitiveness

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The essential relationship to fat in the Middle Paleolithic, and especially to the yellow marrow, explains the importance of addressing this issue of butchery cultural practices through the study of bone fracturing gestures and techniques. In view of the quasi-systematization of bone marrow extraction in many anthropized archaeological levels, this butchery activity had to be recurrent, standardized and counter-intuitive. Thus, the highlighting of butcher traditions made possible by the analysis of the distribution of percussion marks within fossil assemblages, in particular by opposition at patterns resulting from an intuitive practice. Thus, we carried out an experiment that focus at the intuitive way of fracturing bones to extract marrow, involving volunteers with no previous experience in this butchery activity. The objective of this experiment was to highlight the presence or absence of a distribution pattern for percussion marks in an intuitive context by comparing several long bones and individuals. Thus, we wanted to evaluate the influence of the morphological specificity of the element and the specific characteristics of volunteers on the distribution of percussion marks during marrow extraction. The comparison of the different behaviours of volunteers during bone fracturing with the production of remains and marks on bone surfaces highlighted the variables that most influence intuitive model. We selected twelve from a larger experiment that resulted in the fracturing of more than 360 long bones. Each of the experimenters broke a series of ten long bones, the same element. Subsequently, we compared the data collected during the experiment with the data from the laboratory study of the remains. Then, we applied an innovative GIS (Geographic Information System) method to analyze the distribution of percussion marks to highlight recurrent patterns. One of the most significant results of our article shows the existence of significant concentrations of percussion marks, regardless of the volunteers' behaviour during bone fracturing. The predominance of two factors explains the distribution patterns that emerge from our analysis: for humerus, radio ulnas and tibias, the morphology of each element seems to constrain the location of percussion marks, while for femurs; individual choices have more weight in this distribution. In addition, we have observed that at different levels of our analyses, the bone response to fracturing may be totally opposite (quantity of bone marrow, marrow quality, number of blows, difficulty felt, number of fragments produced, type of marks registered), particularly regarding the results for radio-ulnas and tibias. Subsequently, it would

be most interesting to compare the intuitive models that we were able to highlight through spatial analysis with the distributions of percussion marks registered in fossil assemblages. It would thus be possible to propose new hypotheses on butchering practices based on the results presented in this work.

III. 5. 1. Résumé long en français

Le rapport essentiel à la graisse au Paléolithique moyen, et tout particulièrement à la moelle jaune, explique tout l'intérêt d'explorer la question des pratiques culturelles bouchères au travers de l'étude des gestes et des techniques de la fracturation osseuse. Au vu de la quasi systématisation de l'extraction de la moelle dans de nombreux niveaux archéologiques anthropisés, cette activité bouchère devait alors être récurrente, standardisée et contre-intuitive. Ainsi, l'hypothèse d'une mise en évidence de traditions bouchères par l'analyse de la distribution des marques de percussion au sein d'assemblages fossiles, nous est apparu possible.

Ce travail présente une large réflexion sur la distribution des marques de percussion sur les os longs lors de l'extraction de la moelle jaune. Dans cette optique, nous avons réalisé une expérimentation qui s'est intéressée à la manière intuitive de fracturer les os pour en extraire la moelle, impliquant des volontaires n'ayant aucune expérience préalable dans cette activité bouchère. Nous avons croisé les données enregistrées lors de la fracturation avec celles issues de l'étude des restes en laboratoire. Pour cela, les comportements des individus ont été décortiqués : le nombre de coups donnés, la difficulté ressentie, la quantité de moelle récoltée, la qualité de la moelle, la position de l'os lors du coup, l'utilisation de l'enclume, la saisie du percuteur et la position de l'individu. De même, nous avons pris en compte diverses données issues de la fracturation : le nombre de restes, le nombre et le type de marques produites et leur localisation. Concernant, l'emplacement des marques, cette étude s'inscrit dans la continuité du précédent article. Chaque trace de percussion a été enregistrée sur le logiciel ArcGis. Puis, nous avons, appliqué la méthode d'analyse spatiale des Points Chauds Optimisés, mise en place par T. Stavrova, afin d'identifier des zones de concentration de ces marques.

Par le biais de cette expérimentation, nous avons cherché à vérifier si les différents comportements des individus pouvaient influencer la distribution des marques de percussion et si, au fur et à mesure des essais, les individus développaient une manière plus efficace de fracturer les os et ce en fonction de l'élément frappé. Sur la base des résultats présentés dans Stavrova *et al.* (2019) et Moclan & Dominguez-Rodrigo (2018), nous avons voulu savoir si la morphologie de l'élément contraignait plus la répartition des marques de percussion que les particularités inter-individuelles. Enfin, en prenant compte les différentes données enregistrées, nous avons essayé de savoir si les différents éléments osseux testés pouvaient répondre différemment au coup et par là-même à la fracture.

Pour cela, nous avons choisi d'étendre l'échantillon utilisé pour créer la méthodologie SIG à 12 séries pour chacun des quatre éléments fracturés (120 os au total). Nous avons sélectionné

douze individus d'une plus large expérimentation ayant conduit à la fracturation de plus de 360 os longs. Chacun des expérimentateurs a cassé une série de dix os long, toujours le même élément. Par la suite, nous avons comparé les données récoltées durant l'expérimentation avec les données issues de l'étude en laboratoire des restes produits par la fracturation. Puis, nous avons appliqué une méthode novatrice SIG (Système d'Information Géographique) pour analyser la distribution des marques de percussion pour mettre en évidence des modèles récurrents.

D'une part, nos résultats illustrent parfaitement la diversité des comportements des volontaires durant l'expérimentation. Certains adoptent tour à tour des positions différentes, alors que d'autres se fixent dans une unique position pour tous leurs essais. De même, la technique de percussion ou la manière dont les expérimentateurs saisissent l'os ou le percuteur et la manière dont ils le positionnent ou encore l'utilisation des outils mis à leur disposition, tout ceci varie d'un individu à l'autre. Nous avons illustré les différentes positions choisies par les volontaires et la manière de saisir ou positionner l'os durant la fracturation osseuse. Les volontaires ont adopté la position debout, à genou, un genou à terre, accroupi ou encore assis. Ils ont positionné l'os à plat sur l'enclume ou sur le sol, en porte à faux sur l'enclume avec une des portions articulaires posées au sol ou tenu par l'expérimentateur, posé sur deux petites enclumes. Lorsqu'ils ont utilisé la technique de percussion lancée, certains ont choisi de saisir l'os par une extrémité ou les deux pour fracturer la diaphyse contre l'enclume (Figure 9).

D'autre part, un des résultats les plus significatifs de notre article démontre l'existence de concentrations significatives des marques de percussion, indépendamment du comportement des volontaires durant la fracturation osseuse. La prédominance de deux facteurs expliquant ces modèles de distribution émerge de notre analyse. Pour les humérus, les radio-ulnas et les tibias, la morphologie de chaque élément semble contraindre la localisation des marques de percussion, alors que pour les fémurs, les choix des individus ont plus de poids dans cette répartition. En outre, nous avons observé qu'à différents niveaux de nos analyses, la réponse des os à la fracturation peut être totalement opposée (quantité de moelle, qualité de la moelle, nombre de coups, difficulté ressentie, nombre de fragments produits, type de marques enregistrés), notamment concernant les résultats relatifs aux radio-ulnas et aux tibias. Par la suite, il s'est avéré intéressant de comparer les modèles intuitifs que nous avons pu mettre en évidence grâce à l'analyse spatiale avec les distributions de marques de percussion enregistrées dans les assemblages fossiles. Il a été, ainsi possible de proposer de nouvelles hypothèses sur les pratiques bouchères sur base des résultats présentés dans ce travail (Chapitre IV).

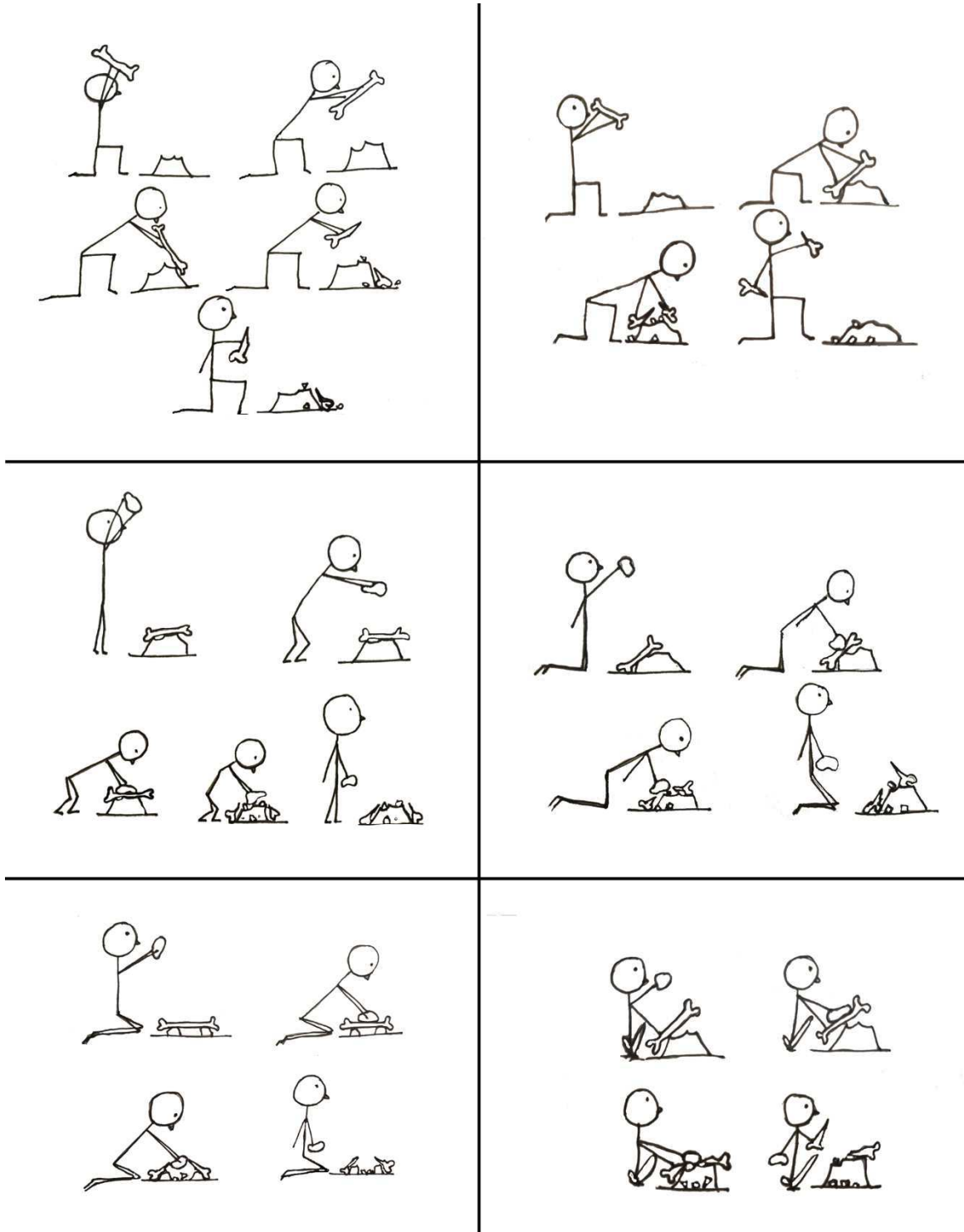


Figure 9: Illustration des différentes positions adoptées par les expérimentateurs pour fracturer les os longs

*Approche techno-culturelle de la fracturation des os longs chez les Néandertaliens (Sud-Ouest de l'Europe, MIS 5-3) :
une systématisation des gestes ?*

*III. 5. 2. Publication n°3***A way to break bones? The weight of intuitiveness**

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Abstract:

The essential relationship to fat in the Middle Paleolithic, and especially to the yellow marrow, explains the importance of addressing this issue of butchery cultural practices through the study of bone fracturing gestures and techniques. In view of the quasi-systematization of bone marrow extraction in many anthropized archaeological levels, this butchery activity had to be recurrent, standardized and counter-intuitive. Thus, the highlighting of butcher traditions made possible by the analysis of the distribution of percussion marks within fossil assemblages, in particular by opposition at patterns resulting from an intuitive practice. With this in mind, we carried out an experiment that focus at the intuitive way of fracturing bones to extract marrow, involving volunteers with no previous experience in this butchery activity. The objective of this experiment was to highlight the presence or absence of a distribution pattern for percussion marks in an intuitive context by comparing several long bones and individuals.

Thus, we wanted to evaluate the influence of the morphological specificity of the element and the specific characteristics of volunteers on the distribution of percussion marks during marrow extraction. Indeed, a previous study was able to show the possible existence of intuitive patterns of distribution of these traces according to the elements (Stavrova et al. 2019). In addition, the comparison of the different behaviours of volunteers during bone fracturing with the production of remains and marks on bone surfaces highlighted the variables that most influence the creation of an intuitive model. We selected twelve from a larger experiment that resulted in the fracturing of more than 360 long bones. Each of the experimenters broke a series of ten long bones, always the same element. Subsequently, we compared the data collected during the experiment with the data from the laboratory study of the remains. Then, we applied an innovative GIS (Geographic Information System) method to analyze the distribution of percussion marks to highlight recurrent patterns.

One of the most significant results of our article shows the existence of significant concentrations of percussion marks, regardless of the volunteers' behaviour during bone fracturing. The predominance of two factors explains the distribution patterns that emerge from

our analysis: for humerus, radio ulnas and tibias, the morphology of each element seems to constrain the location of percussion marks, while for femurs, individual choices have more weight in this distribution. In addition, we have observed that at different levels of our analyses, the bone response to fracturing may be totally opposite (quantity of bone marrow, marrow quality, number of blows, difficulty felt, number of fragments produced, type of marks registered), particularly regarding the results for radio-ulnas and tibias. Subsequently, it would be most interesting to compare the intuitive models that we were able to highlight through spatial analysis with the distributions of percussion marks registered in fossil assemblages. It would thus be possible to propose new hypotheses on butchering practices based on the results presented in this work.

Introduction

Lipids are essential nutrients for the human organism. During the Palaeolithic, fat was even more important, due to its role in the gluconeogenesis metabolism, synthesizing glucose from non-carbohydrate precursors (Costamagno and Rigaud, 2014; Holt et al., 2018; Speth, 2010). At that time, various flora and fauna provided lipid resources but their accessibility was largely influenced by environmental contexts. Lipids were found in oilseeds, such as hazelnuts. However, cold and dry periods were characterized by a low vegetal biomass during which animal resources represented the most important food resources (Benazzi et al., 2015; Binford, 1981; O'Connell et al., 1992; Speth, 2010). The red marrow present in bone epiphyses and yellow marrow from the diaphysis were both important resources of fat from animal carcasses. Marrow was even the most widely available fat resource during the winter (Abe, 2005; Binford, 1978; Brugal and Defleur, 1989; Costamagno and David, 2009; Hardy et al., 2006; Kuntz et al., 2016; Speth and Spielman, 1983). Indeed, the recovery of yellow marrow was quasi-systematic among Palaeolithic hunter-gatherers, and particularly for Neanderthals (Noe-Nygaard, 1977; Patou-Mathis, 1985; Speth, 1989; Speth et al., 2012). Prehistorians noted widespread evidence of marrow extraction through long bone breakage at Middle Palaeolithic sites (e.g.,: Blasco and Fernández Peris, 2012; Daujeard et al., 2017, 2012; Joana et al., 2014; Marín et al., 2017; Romandini et al., 2014; Valensi et al., 2013).

The traces left on bones by marrow recovery are mainly percussion marks. For several decades, percussion marks and long bone breakage methods have been extensively studied (Boulestin, 1999; Capaldo and Blumenschine, 1994; Fisher, 1995; Gifford-Gonzalez, 2018; Patou-Mathis, 1985; White, 1992). Since the beginning of the twentieth century and up until now, archaeological experiments on long bone breakage have been carried out to characterize

percussion marks and their location (e.g.,: (Blasco et al., 2014; Blumenschine and Selvaggio, 1988; Brugal and Defleur, 1989; Galán et al., 2009; Martin, 1910; Moclán and Domínguez-Rodrigo, 2018; Noe-Nygaard, 1977; Patou-Mathis, 1985; Pickering and Egeland, 2006). Fracture patterns have also been extensively studied on different states of bone preservation: fresh, dry, weathered, fossilized but also heated, frozen, boiled (Alhaique, 1997; Karr and Outram, 2012; Lacroix, 2011; Outram, 2002; Villa and Mahieu, 1991). The authors based their experimental protocols on ethnographic works studying current populations of hunter-gatherers (e.g.,: Abe, 2005; Binford, 1981; Costamagno and David, 2009; Enloe, 1993; Oliver, 1993; ; Stiner et al., 2011; Yravedra et al., 2017). More recently, the use of new methodological approaches (e.g., geometric morphometrics, 3D modelling or GIS analyses of distribution along the diaphysis...) presents new challenges for the experimental study of marrow recovery.

Some recent studies have focused on the distribution of percussion marks on long bones to approach the subsistence behaviours of past hominins (Blasco et al., 2013; Masset et al., 2016; Moclán and Domínguez-Rodrigo, 2018; Vettese et al., 2017). One of these studies highlighted for the first time a pattern of non-random bone breakage and interpreted it as a product of butchery traditions among Neanderthals (Blasco et al., 2013). Through comparisons with an experiment performed by non-trained volunteers, the authors established that this systematic pattern differed from intuitive patterns. In addition, Moclán and colleagues (2018) proved that the morphology of the skeletal element from which marrow is extracted could influence the distribution of percussion marks.

We conducted a large-scale experiment to test how non-trained individuals recover marrow. Indeed, in order to identify butchery traditions in Palaeolithic sites, it is necessary to differentiate know-how from intuitiveness. The definition of a butchery tradition is a systematic and counterintuitive pattern shared by a same group. The immediate apprehension of the non-trained butcher to break a bone is influenced by numerous variables, including anatomical constraints (Blasco et al., 2013; Moclán and Domínguez-Rodrigo, 2018). Individuals who regularly break long bones acquire an empirical approach and develop specific skills that enhance efficiency (Pickering and Egeland, 2006). Hence, their skills include habits and preferences gained by experience and/or group traditions. This know-how cannot be assessed without differentiating between physical bone features and socio-cultural practices.

Thus, our aim is to experimentally test whether the inter-individual specificity of long bone morphology may have some influence on the distribution of percussion marks. Based on (GIS) spatial analysis of percussion marks on the bone surface, we also test the existence of a

preferential pattern regarding the intuitive breakage of long bones. Moreover, we intend to verify whether non-experienced volunteers develop their own method to improve efficiency, such as an auto-learning process. Finally, it should be possible to grasp the influence of each bone structure by comparing the elements between them and by assessing the performance of individuals on the same types of bones. This allows for the comparison of behaviours and the influence of behaviour on the production of bone remains and the marks recorded.

Material and Methods

Material

The studied sample includes 120 limb bones (humeri, radio-ulnas, femurs and tibias) from adult cows at least 24 months old. A slaughterhouse supplied this experimental series, with 30 specimens of each element, both left and right (Table 1). Professional butchers defleshed the carcasses. During the process, they cut the metapodials with cutting pliers. Thus, these bones are absent from the present experiment. After the reception of the bones, they were stored for less than a week in a fridge at 4 °C. In addition, the elements broken by individuals 11 and 12 were frozen for 40 days and thawed for three days in the same fridge before the experiment (temperature: 4°C).

Individual number	Element	Right	Left
1	Humerus	3	7
2	Radio-ulna	6	4
3	Femur	6	4
4	Tibia	2	8
5	Femur	4	6
6	Tibia	4	6
7	Humerus	5	5
8	Femur	6	4
9	Radio-ulna	6	4
10	Tibia	3	7
11	Humerus*	4	6
12	Radio-ulna*	3	7

*Table 1: Data about the bone element broken by each experimenter (number of ID, element used, side). * These bones were frozen.*

The experimental series involved 12 volunteers (Table 2) without any experience in bone breakage: eight men (mean age =34 years old; SD = 11.1 years) and four women (mean age = 31 years old; SD = 7.1 years). Five individuals had theoretical knowledge of long bone anatomy and one (individual number 1) was used to flaking lithic tools. Each experimenter broke a series of 10 long bones of the same element. The number of tests is defined by the order in which each bone is broken one after the other in a series of 10. To avoid selection biases, the bones were stacked in a disordered pile when they were presented to the experimenters. Experimenters were isolated from each other so they could not observe how the others broke the bones. No demonstration was performed. Before the experiment, they only received one instruction: break the bone to extract the highest quantity and quality of yellow marrow suitable for consumption. The breakage activity lasted for two to three hours depending on the bone element and the individual. Experimenters had at their disposal a non-retouched quartzite hammerstone weighing about 2 kg, a limestone anvil, a plate to deposit the marrow and a wooden stick. The periosteum was not removed before breakage. Experimenters stopped once they had extracted as much bone marrow as they could, and then collected it in the plate and weighed it.

Individual number	Age	Size (cm)	Weight (kg)	Sex	Used hand	Sport Practice	Bone knowledge	Broken bone element
1	29	167	53	W	Right	Yes	Yes	Humerus
2	40	174	82	M	Right	No	Yes	Radio-ulna
3	25	185	78	M	Right	Yes	Yes	Femur
4	30	186	80	M	Right	Yes	No	Tibia
5	51	160	59	W	Left	No	Yes	Femur
6	22	190	95	M	Left	Yes	No	Tibia
7	39	169	63	M	Right	Yes	No	Humerus
8	23	182	95	M	Right	No	Yes	Femur
9	23	167	58	W	Right	Yes	No	Radio-ulna
10	46	169	74	M	Right	Yes	No	Tibia
11	25	158	73	W	Right	Yes	No	Humerus
12	29	178	80	M	Right	Yes	No	Radio-ulna
Average	31.8	173.8	74.2					
Stand. dev.	9.8	10.4	13.7					
Maximum	51	190	95					
Minimum	22	158	53					

Table 2: Data about the volunteers for each series (W: Women; M: Men; Stand. Dev.: Standard Deviation).

Our experiment involved volunteers with no empirical knowledge of recovering marrow using long bone breakage. Some were archaeologists or palaeontologists, the rest of the experimenters worked in other fields with no relation to skeletal anatomy or bone tissue properties. The first category of experimenters were familiar with bone morphology and structure as a study object only. Thus, the approach to the long bones during marrow recovery was as intuitive as possible, independently of the experimenters' age or sex. Besides, the volunteers broke a series of ten bones one after another. This process allowed novice experimenters to self-assess and eventually learn from their mistakes.

After breakage, all the fragmented remains were grouped together in a bag with an identification code. The bones were boiled during 2 or 3 hours, to remove the grease and to soften the flesh, and then placed in an oven at 40°C in a solution of water and Papain (papaya enzyme) for 48 hours. Then, they were soaked in a solution of water and sodium perborate for 24 hours, before being air-dried. The material is currently kept in the Institut de Paléontologie Humaine (Paris).

Data acquisition

During the experiments, an observer recorded the following variables: the series number, element laterality, position of the individual, the way the hammerstone was grasped, the position of the bone, the use of the anvil and the number and location of blows. For these latter, we defined an area as a long bone portion associated with a side (Figure 1). In order to evaluate the progression of volunteers during the experiment, from the first try to the end of the operation, we recorded task difficulty evaluation and the number of blows. We asked the experimenters to auto-evaluate the difficulty encountered during marrow recovery on a scale from 1 to 5, (1 = very easy; 5= very hard), considering mainly the opening of the medullary cavity and marrow extraction. This auto-evaluation resulted in an empirical comparison between long bones. The aim of this auto-evaluation was to assess whether volunteers progressed and developed an efficient method to extract marrow or if tiredness along with the long period of effort affected their capabilities. For quality control purposes, the experimenter and observer evaluated results on a

scale from 1 to 5, 1 referring to contaminated marrow containing abundant splinters and 5 being very clean marrow.

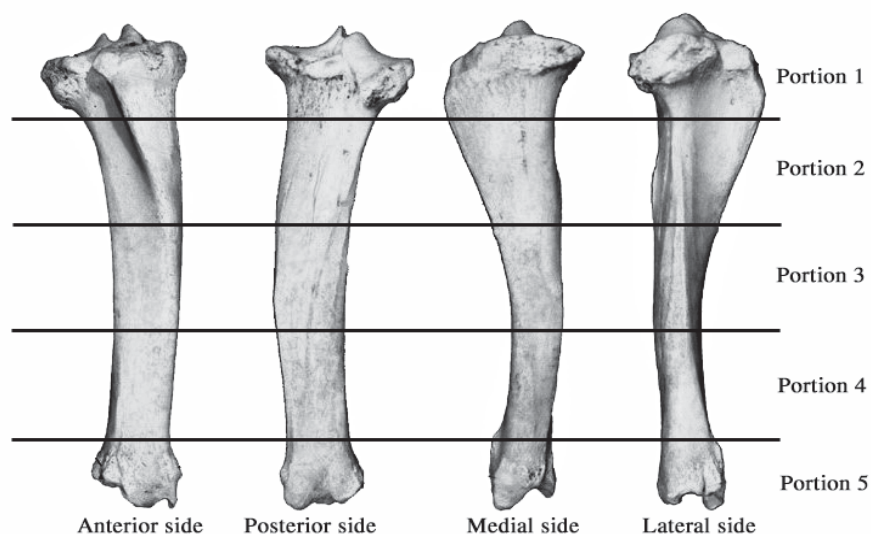


Figure 1: Bone areas by portions and sides. Portion 1 (p1): proximal articular end; Portion 2 (p2): proximal diaphysis; Portion 3 (p3): medial diaphysis; Portion 4 (p4): distal diaphysis; Portion 5 (p5): distal articular end and Anterior (a), Posterior (p), Medial (m) and Lateral (l) side (after the drawing by Castel (2010), reference A. Grunwald - © 2016 <https://allisongrunwald.wordpress.com/>).

The number of identified specimens (NISP), the number of undetermined specimens (NUSP) and the total number of specimens (NSP) were recorded. As the exact location of the percussion marks is necessary, only identified fragments for each bone element were included. Besides, throughout the treatment and the study of each bone, all the remains of one element were kept together, but the NUSP were splinters that we could not refit. Remains that could not be refitted were not considered in the following analysis. The width and length of fragments were measured using a digital caliper. The location of the percussion marks on the bone fragments was analysed according to the GIS protocol developed by Stavrova et al. (2019). The outline of the cortical surface of each identified fragment was digitized using georeferenced photographic images representing the four-sided visualization of each bone as a base.

Bone surface modifications were identified and recorded with the naked eye and 15-20x lens. The centre of each percussion mark was recorded in ArcGIS with a point symbol, based on the anatomical landmarks of each bone (e.g.,: foramen, crest) (Stavrova et al. 2019). In accordance with the terminology of Vettese et al. (submitted), five types of percussion marks were recorded: adhering flakes, crushing marks, flakes, percussion notches, ovoid or triangular percussion pits and grooves. The number of percussion marks (NPM) and the marks related to percussion (i.e., striations, microstriations and pseudo-notches) were also noted. These last marks were not taken

into account in the total number of percussion marks. In addition, we excluded the flake because if we had taken into account the flake and the notch, which were respectively positive and negative for the same percussion mark, we would have counted the percussion point twice. In this analysis, percussion marks were divided into two groups: 1) crushing marks, notches and adhering flakes (called "CNA") and 2) pits and grooves (called "Pits"). The "CNA" grouped the percussion marks related to cracking and fractures whereas "Pits" were only produced by incipient percussion or the rebound effect.

Distances between percussion marks were calculated in ArcGIS and the "Optimized Hot Spot analysis" tool was used to evaluate and highlight zones with high concentrations of percussion marks. This tool identifies statistically significant spatial clusters of high concentrations (hot spots) and low concentration of percussion marks (cold spots). The number of percussion marks recorded for each series complies with the minimum of 30 features required to conduct the analysis (Stavrova et al. 2019).

The data collected during the experiment were compared to the data analysed in the laboratory in order to understand which variables of the experimenters' behaviour could influence fragmentation and the production of percussion marks. Spearman's rho was used to test the correlation between the data collected during the experiment (i.e., number of blows and marrow weight) and the data recorded on the bones after treatment (i.e., number of remains and number of percussion marks). Moreover, in order to evaluate auto-learning and individual improvement, we tested the Spearman correlation of the number of attempts according to the number of blows for each individual. We presented ρ of Spearman. To highlight the evolution of the number of blows between the beginning and end of the experiment for each of the volunteers, we compared, on the one hand, the two averages of the first three and the last three trials and, on the other hand, the first five and the last five trials using a non-parametric Mann-Whitney U test. Indeed, the t-test hypothesis was never respected for our data (i.e., the normality and equivalence of the variance of data). We propose an Efficiency Index calculated by dividing the mass of marrow extracted from each bone by the number of blows. This Efficiency Index represents the relationship between a form of expended energy and a form of recovered energy. The higher the Efficiency Index, the more marrow was extracted with the least number of blows. To test a possible evolution of the Efficiency Index between the three first and the last three tries and also between the five first and the last five attempts, we compared the two averages using the Mann-Whitney U Test, when assumptions for the t-test were not respected. We used the chi-squared test for the scale of auto-assessment. As Cochran's rule was not respected, we used the Fisher exact test to check the independence between the scale of marrow quality of the different

elements. The correlation coefficients and the tests were computed using R software (R Core Team, 2019). We use an alpha of 0.05 for all the tests.

Results

Data recorded during the experiment

Bone and individual positions: different ways to break a bone

The position of the bone elements and the position of the volunteers themselves varied during the breaking process (Table 3). Five different positions chosen by the experimenters were observed. The majority chose the squatting position (45%), followed by the kneeling position (43%). The standing position was rarely selected. Only one individual broke bones in a seated cross-legged position (individual n°2). A minority of the experimenters adjusted their positions during breakage (five individuals: n°2, 4, 8, 9 and 11; 42%). Individual n°7 remained in the squatting position during the entire experiment, but nonetheless tried the standing position once at the eighth try, without repeating it. Volunteer n°10 was the only one who did not adopt and maintain a position. By contrast, four experimenters developed some kind of habit after a certain number of attempts. Individual n°3, after three tries, chose the seated position and individual n°6 selected a kneeling position after two tries. Volunteer n°5 developed a routine from the sixth attempt onwards. For each attempt, she started in a standing position, then kneeled down, and she finished in a squatting position. Individual n°1 squatted for all the attempts and half the time, she stood to hit the bone on the anvil. Only one volunteer tested almost all the positions during the experiment (individual n°12). Nonetheless, after two tries, he switched back to a squatting or kneeling position.

Regarding the choice of hand to grasp the hammerstone, only one individual used the left hand, although two volunteers were left-handed and one was ambidextrous. Therefore, the use of both hands did not seem to be dependent on laterality. All the volunteers breaking the radio-ulna used both hands at least once to grasp the pebble, which was never the case for the volunteers who broke the tibias. The individuals who used both hands were both men and women.

We distinguished five ways to position the long bone in order to open its medullar (Table 3). Ten of the volunteers used the anvil at least once. Two experimenters (individuals n°8 and n°11) did not use the anvil at all, but positioned the bones directly on the ground. One individual (individual n°7) selected the batting technique. He hit the bone directly on the anvil with his hands grasping each epiphysis in order to separate portion 1 from the diaphysis. Then, he laid the largest fragment on the anvil and pursued breakage using the pebble to recover as much marrow as

possible. He began using this mixed technique after two tries and repeated it for the next attempts until the end of the series. He judged this mixed technique more efficient than only the hammerstone on anvil technique. One-third (33%) of the volunteers always positioned their bones in the same way during the experiment. Therefore, the majority of the experimenters varied bone position during each try. We noticed that volunteers experienced some difficulties in stabilizing the bone in order to hit it, especially for the radio-ulnas. Sometimes the bone slipped and the blow was less efficient. Some experimenters used an extra stone, their knees or the anvil to block the bone and keep it from slipping.

Element Individual number	Squatting position	Standing position	Seated position	Kneeling position	One knee on ground and one on kneeling	Right grasp hand	Left grasp hand	Both grasp hand	On the anvil	One side on the anvil	Batting	One side on the anvil, the other on the ground	On the ground
Femur	7 (23%)	4 (13%)	10 (33%)	13 (43%)	2 (2%)	20 (67%)		12 (40%)	18 (60%)			1 (3%)	16 (53%)
3			10	3	2	10		2	10				
5	6	4						10	8			1	6
8	1			10		10							10
Humerus	20 (67%)	1 (3%)	3 (10%)	8 (27%)		30 (100%)		9 (30%)	20 (67%)	3 (10%)	9 (30%)		10 (33%)
1	9	1	2			10			10				
7	10					10		8	10	3	9		
11	1		1	8		10		1					10
Radio- Ulna	16 (53%)		11 (36%)	5 (17%)	3 (10%)	23 (77%)		13 (43%)	16 (53%)			14 (47%)	10 (33%)
2			10			10		2	10				
9	10					3		10	1			5	10
12	6		1	5	3	10		1	5			9	
Tibia	20 (67%)			10 (33%)	6 (20%)	20 (67%)	10 (33%)		26 (87%)	2 (7%)		11 (37%)	
4	10					10			10	2			
6				10			10		10			1	
10	10				6	10			6			10	
Total	63 (53%)	5 (4%)	24 (20%)	36 (30%)	11 (9%)	93 (78%)	10 (8%)	34 (27%)	80 (67%)	5 (4%)	9 (8%)	26 (22%)	36 (30%)

Table 3: Experimenter and bone position for each bone element, percentages were performed by 30 attempts by elements, and by the 120 attempts for the total.

The marrow quantity and quality

In order to extract marrow after breakage, most of the volunteers used the wooden stick we provided, but some preferred selecting their own. Only one individual (n°7) used the bone splinters created during breakage. Some also used their fingers. The radio-ulna was the long bone that yielded the smallest quantity of marrow; it represents 13% of the total collected marrow (Table 4). The quantity of marrow extracted from the femur is twice as high (26%). The volunteers who broke the humeri and the tibias extracted a slightly higher quantity of marrow (around 30%). The total quantity of yellow marrow recovered represented 18 kg. We did not notice high variation among volunteers, except for individual n°5 who recovered a significantly smaller quantity of marrow from the femurs than the other experimenters for the femur series (Supplementary data Figure 1, 2 and 3).

Element	N°indiv	MW (g)		NSP		NISP		NUSP		NB		NPM		Npit		NCNA	
Femur	3	1861	10.20%	259	9.50%	130	9.30%	129	9.80%	641	10.30%	263	5.30%	190	4.80%	73	7.40%
Femur	5	1030	5.60%	202	7.40%	137	9.80%	65	4.90%	496	7.90%	326	6.50%	282	7.10%	44	4.40%
Femur	8	1780	9.80%	222	8.20%	113	8.10%	109	8.20%	179	2.90%	221	4.40%	165	4.10%	56	5.70%
Femur	Total	4671	25.60%	683	25.10%	380	27.10%	303	22.90%	1316	21.10%	810	16.20%	637	15.90%	173	17.50%
Humerus	1	1710	9.40%	290	10.70%	109	7.80%	181	13.70%	573	9.20%	194	3.90%	72	1.80%	122	12.30%
Humerus	7	1737	9.50%	131	4.80%	77	5.50%	54	4.10%	244	3.90%	304	6.10%	217	5.40%	87	8.80%
Humerus	11	1941	10.60%	195	7.20%	84	6.00%	111	8.40%	377	6.00%	367	7.40%	301	7.50%	66	6.70%
Humerus	Total	5388	29.50%	616	22.60%	270	19.30%	346	26.20%	1194	19.10%	865	17.30%	590	14.80%	275	27.80%
Radio-ulna	2	799	4.40%	263	9.70%	119	8.50%	144	10.90%	808	12.90%	180	3.60%	49	1.20%	131	13.20%
Radio-ulna	9	775	4.20%	113	4.20%	80	5.70%	33	2.50%	873	14.00%	503	10.10%	428	10.70%	75	7.60%
Radio-ulna	12	811	4.40%	189	6.90%	73	5.20%	116	8.80%	822	13.20%	942	18.90%	894	22.40%	48	4.80%
Radio-ulna	Total	2385	13.10%	565	20.80%	272	19.40%	293	22.20%	2503	40.10%	1625	32.60%	1371	34.30%	254	25.70%
Tibia	4	1755	9.60%	439	16.10%	192	13.70%	247	18.70%	285	4.60%	280	5.60%	138	3.50%	144	14.50%
Tibia	6	1759	9.60%	175	6.40%	120	8.60%	55	4.20%	753	12.10%	738	14.80%	673	16.80%	65	6.60%
Tibia	10	2290	12.50%	244	9.00%	166	11.90%	78	5.90%	189	3.00%	669	13.40%	590	14.80%	79	8.00%
Tibia	Total	5804	31.80%	858	31.50%	478	34.10%	380	28.70%	1227	19.70%	1687	33.80%	1401	35.00%	288	29.10%
Total		18248		2722		1400		1322		6240		4987		3999		990	

Table 4: Individual number (n°indiv), Marrow Weight (MW), Number of Specimen (NSP), Number of identified specimens (NISP), Number of undetermined specimens (NUSP), Number of blows (NB), Number of percussion marks (NPM), Number of pit (Npit) and Number of crushing marks, of adhering flakes and of notches (NCNA).

The evaluation of the quality of collected marrow shows a low proportion of bad or very bad assessments (10 %) (Table 5). In addition, most of those who made this judgment broke radio-ulnas. Most (2/3) of the recovered marrow was evaluated as good or very good to consume. None of the volunteers who broke the humerus series evaluated the marrow as very consumable. However, more than a half of the volunteers estimated the tibia marrow to be very good. The Fisher exact tests show that the scales of the tested elements were independent (df = 12, p<0.05).

We noted a significant negative correlation between the quantity of marrow and the number of blows. Indeed, the radio-ulna was the element that received the most blows during the experiment and where a smaller quantity of marrow was recovered. Concerning the radio-ulna, we observed a significant negative correlation between the NISP and the quantity of marrow

collected. Besides, we noticed a significant positive correlation between the quantity of recovered marrow and both the NUSP and the number of CNA.

Felt scale	All		Femur		Humerus		Radio-ulna		Tibia	
Very easy	14	11.7%	4	13.3%	2	6.7%	1	3.3%	7	23.3%
Easy	53	44.2%	11	36.7%	21	70%	5	16.7%	16	53.3%
Moderate	28	23.3%	9	30%	4	13.3%	11	36.7%	4	13.3%
Hard	16	13.3%	4	13.3%	1	3.3%	8	26.7%	3	10%
Very hard	9	7.5%	2	6.7%	2	6.7%	5	16.7%	0	0%
Marrow quality scale	All		Femur		Humerus		Radio-ulna		Tibia	
Very bad	3	2.5%	0	0%	3	10%	0	0%	0	0.0%
Bad	9	7.5%	1	3.3%	0	0%	8	26.7%	0	0.0%
Neutral	29	24.2%	7	23%	15	50%	6	20%	1	3.3%
Good	55	45.8%	17	56.7%	12	40%	14	46.7%	12	40%
Very good	24	20%	5	16.7%	0	0%	2	6.7%	17	57%

Table 5: Scales of difficulty felt during the experiment and of the marrow quality auto-evaluated by the experimenters themselves for all the elements and for each one.

The level of difficulty experienced during the experiment and the number of blows

In summary, the experimenters found the activity very easy 14 times, easy 53 times, moderate 28 times, difficult 16 times and very difficult only 9 times. Volunteers who broke the humeri did not encounter any difficulty in most cases (77% easy or very easy). The radio-ulna seems to be more difficult to break (43% hard or very hard and 37% moderate). None of the volunteers who broke a tibia estimated the task to be very difficult. They did not find the task any easier or harder as they progressed. In other words, they did not find the task harder at the beginning because they did not know how to go about it and then easier because they found an efficient technique. Likewise, exhaustion from the activity did not influence whether volunteers experienced more difficulty at the end of the breakage series (Table 5). The difficulty encountered according to the bone element varied significantly (Chi-squared test: $df = 12, X^2 = 73.00362, p < 0.01$).

The results of Spearman's correlation analysis between the number of attempts according to the number of blows for each individual completed these observations. For five individuals (individuals n°1 and n°7 (humerus), individual n°3 (femur) and (individuals n°6 and n°9 (tibia)), the correlation analysis shows a significant negative relationship (Spearman's rank correlation

coefficient results respectively $\rho = -0.81; -0.77; -0.73; -0.93; -0.69$). Regarding the other individual series, the results were not significant (Spearman's rank correlation coefficient results respectively ρ : $n^{\circ}2 = -0.29$; $n^{\circ}4 = 0.54$; $n^{\circ}5 = -0.2$; $n^{\circ}8 = 0.51$; $n^{\circ}10 = 0.41$; $n^{\circ}11 = -0.44$; $n^{\circ}12 = 0.32$).

The results of Spearman's correlation analysis between the number of attempts according to the number of blows for each individual completed these observations. For five individuals (individuals $n^{\circ}1$ and $n^{\circ}7$ (humerus), individual $n^{\circ}3$ (femur) and (individuals $n^{\circ}6$ and $n^{\circ}9$ (tibia)), the correlation analysis shows a significant negative relationship (Spearman's rank correlation coefficient results respectively $\rho = -0.81; -0.77; -0.73; -0.93; -0.69$). Regarding the other individual series, the results were not significant (Spearman's rank correlation coefficient results respectively ρ : $n^{\circ}2 = -0.29$; $n^{\circ}4 = 0.54$; $n^{\circ}5 = -0.2$; $n^{\circ}8 = 0.51$; $n^{\circ}10 = 0.41$; $n^{\circ}11 = -0.44$; $n^{\circ}12 = 0.32$).

The proportion of the number of blows varied over the last attempts depending on individuals. Experimenters $n^{\circ} 1, 3, 7, 9$ reduced their number of hits by half, on average, $n^{\circ}6$ by six between the three first attempts and the last three (Supplementary data figure 1). Volunteer $n^{\circ}12$ increased the average number of blows after the three first tries. However, if we consider the same individual breaking the same element during the whole experiment, we did not observe a significant difference between the five first and the last five attempts. We found similar results between the three first and the last three, except for the humerus (p -value = 0.0254) (Supplementary data Table 2).

The bi-plots showing the number of blows and marrow weight did not display any linearity in the data regarding each element (Supplementary data Figure 3). When we examine bone element type, the volunteers who broke the radio-ulnas reveal reduced Efficiency Index compared to the other elements (Figure 2; EFI all). On the other hand, the experimenters who broke the tibias had a high average Efficient Index (>5). There was marked variation between the volunteers who broke the humeri and the femurs, especially for the first three attempts (Figure 2; EFI 3). Between the first three and the last seven tries, the EFI of the volunteers who broke the tibias varied, like individual $n^{\circ}8$. At the individual level, two-thirds of the volunteers increased their EFI between the first five and last five tries ($n^{\circ}3, 5, 1, 7, 11, 9, 6, 10$). Similarly, more than half the individuals augmented their EFI between the first and last three ($n^{\circ}3, 1, 7, 11, 2, 9, 6$) (Supplementary data Table 1). However, regarding all the experimenters, the Wilcoxon signed rank test did not show a significant difference between the first five and the last five tries or between the first three and the last three tries ($p < 0.05$) (Supplementary data Table 2 and Figure 2). We observed similar results regarding each element ($p < 0.05$).

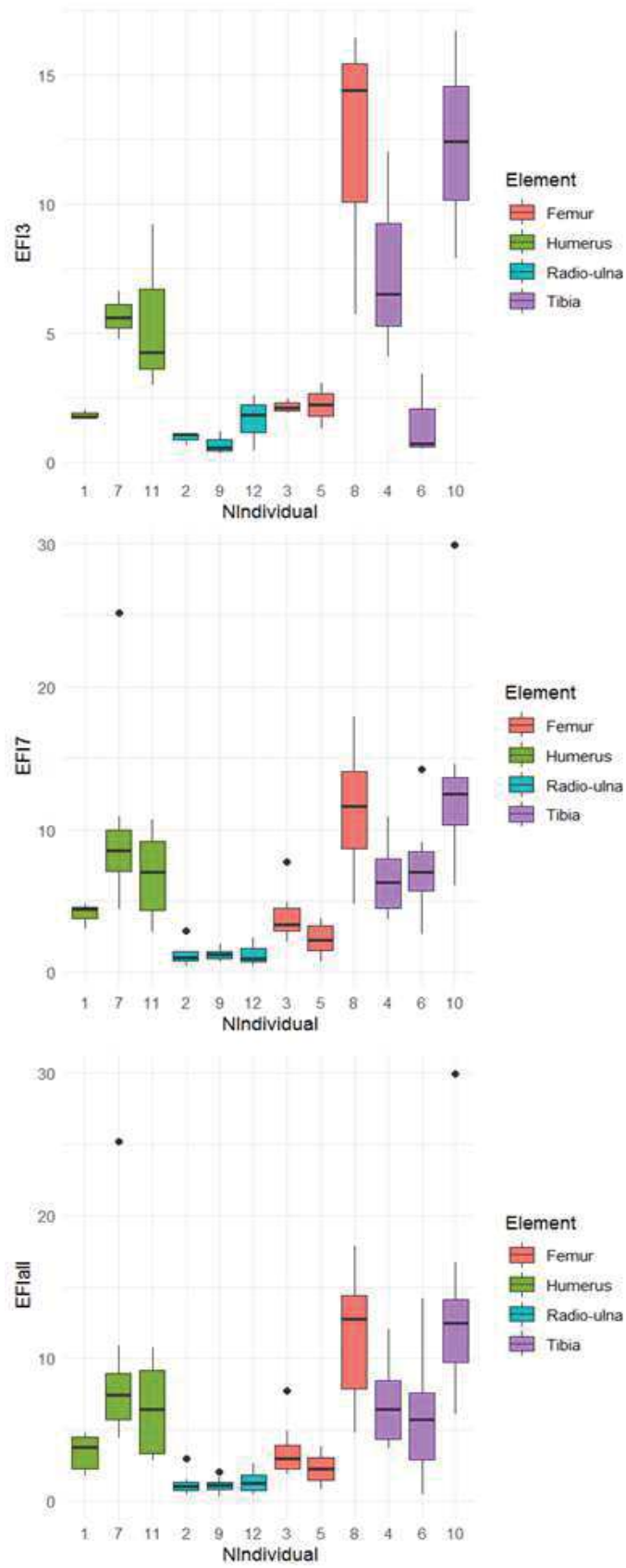


Figure 2: Box plots of the Efficiency Index by Individual during the experiment regarding the third first tries, the last seventh tries and all tries.

Data recorded on the faunal assemblage obtained

Bone fragmentation

The experiments yielded 2,722 bone remains, among which 1,400 were refitted (Table 4). The NSP of the tibias (32%) is higher than for the other elements, which are almost identical. Likewise, the tibia NISP is the highest (34%) and the NISP of the humerus and radio-ulna are the lowest (19%). Nonetheless, we noticed that the average NUSP is around 25% for all the elements. We did not observe marked variability between individuals regarding the NISP, NUSP and the NSP (Supplementary data Figure 4). However, volunteer n°4 produced more numerous NUSP, which also affected the NSP. According to our application of the Spearman's rank correlation test, the NSP was positively correlated with both the NUSP and the NISP for all the elements (all elements: $\rho = 0.44$ and $\rho = 0.76$; humerus: $\rho = 0.57$ and $\rho = 0.79$; radio-ulna: $\rho = 0.39$ and $\rho = 0.68$; femur: $\rho = 0.51$ and $\rho = 0.8$; tibia: $\rho = 0.51$ and $\rho = 0.8$). The NUSP and the NISP were also positively correlated between them (all elements: $\rho = 0.91$; humerus: $\rho = 0.93$; radio-ulna: $\rho = 0.91$; femur: $\rho = 0.9$; tibia: $\rho = 0.9$) (Supplementary data Figure 5).

Number of percussion marks

For one-third of the series, we recorded more percussion marks than the number of blows given by the experimenters (Table 4). This anomaly was observed for one individual for each bone element. Three of the individuals who produced a high number of percussion marks used an anvil, but this was not the case for volunteer n°8. The tibia and radio-ulna series presented numerous percussion marks (around 33%), corresponding to almost twice as many percussion marks as the femurs and humeri. We recorded the most abundant pits and grooves on the tibia and the radio-ulna series. The other percussion marks represented around 27% for all elements, with slightly less on the femurs (18%). Furthermore, these marks display a lower standard deviation ($SD = 33$) than the pits ($SD = 263$) or all the percussion marks combined ($SD = 245$). We observed an inter-individual difference, in particular for the first series of the humeri, radio-ulnas and tibias. A different observer recorded these series.

According to our application of the Spearman's rank correlation test, we noted a significant positive correlation between percussion marks with the number of pits and grooves on one hand, and the number of crushing marks, adhering flakes and notches ("CNA"), on the other, for all the long bones except the tibias ($\rho_{NPM/Npit}$: humerus = 0.95; radio-ulna = 0.96; femur = 0.95; tibia = 0.93; all elements = 0.93; $\rho_{NPM/NCAN}$: humerus = 0.35; radio-ulna = 0.7; femur = 0.35; tibia = -0.07; all elements = 0.48). The number of pits and grooves in the tibia series depended on the number of percussion marks, whereas the other marks were independent. The number of percussion marks causing a fracture ("CNA") was not significantly correlated with the other

percussion marks (pits) ($\rho_{\text{NCAN/Npit}}$: humerus = 0.16; radio-ulna = 0.59; femur = 0.29; tibia = -0.32; all elements = 0.24). However, we observed a positive correlation for the radio-ulna series and a negative one for the tibia series. The number of percussion marks producing fractures (“CNA”) was positively correlated with the NSP for the humerus series ($\rho = 0.34$). We observed a significant positive correlation between the “CNA” percussion marks and the weight of marrow and the NUSP for femurs and tibias (respectively, femurs: $\rho = 0.5$; $\rho = 0.38$ and tibias: $\rho = 0.62$; $\rho = 0.92$). In addition, the number of pits and grooves on the tibias was correlated positively with the NISP and the NSP (respectively: $\rho = 0.5$; $\rho = 0.38$). Finally, the radio-ulnas showed a positive correlation between percussion marks causing breakage (“CNA”) and the number of blows ($\rho = 0.39$) (Supplementary data Figure 5).

The graph for the PCA analyses showed more differences between the tibia series on one hand and the radio-ulna and humerus series, on the other, in particular on the second dimension (Figure 3). These differences are mainly due to the NSP and the Efficiency Index. On the first dimension, radio-ulnas and humeri are opposed by the number of blows and by the number of tries.

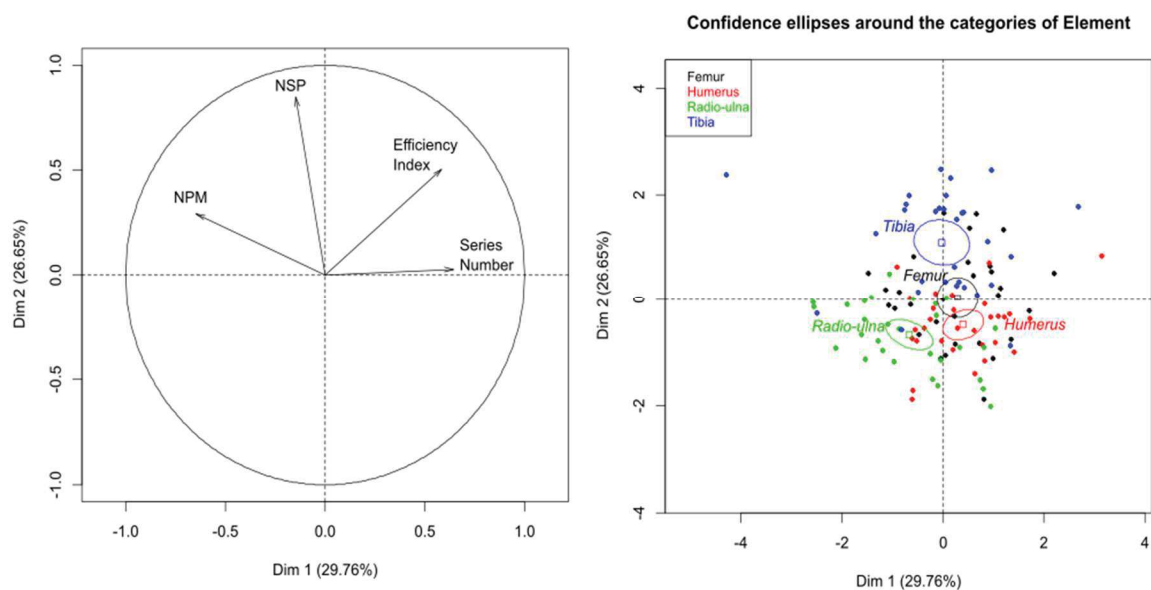


Figure 3: PCA regarding the number of remains (NSP), the number of percussion marks (NPM), the Efficiency Index and the number of attempts (Series Number) with ellipses at 0.95.

Percussion mark types and spatial distribution

We observed around 5,000 percussion marks on the identified fragments (Table 6). Pits were the most numerous (78%) and grooves were the least frequent marks (2.6%). Both triangular and ovoid pits were present, but the former were less numerous. We recorded more pits on the tibias

and radio-ulnas than on the other bone types. Adhering flakes and notches represented 15% of all the percussion marks. Crushing marks were one of the least numerous traces (4.9 %), and were often located close to the articular portions. We recorded fewer crushing marks and more grooves on tibias compared to the other long bones. Conversely, we documented the most numerous crushing marks and adhering flakes on the humeri. We noted high variation in the number of pits and adhering flakes depending on the observers who documented the percussion marks. This difference in recording did not influence the number of other marks to the same degree. We also observed inter-individual variability, in particular for the radio-ulna series.

Element/ N°indiv	Percussion notch		Adhering flake		Triangular pit		Ovoid pit		Grooves		Crushing marks		Total PM
Femur	85	10.5%	26	3.2%	41	5.1%	574	70.9%	22	2.7%	62	7.7%	810
3	45	17.1%	10	3.8%	9	3.4%	173	65.8%	8	3.0%	18	6.8%	263
5	15	4.6%	5	1.5%	14	4.3%	257	78.8%	11	3.4%	24	7.4%	326
8	25	11.3%	11	5.0%	18	8.1%	144	65.2%	3	1.4%	20	9.0%	221
Humerus	80	9.2%	93	10.8%	95	11.0%	462	53.4%	33	3.8%	102	11.8%	865
1	39	20.1%	66	34.0%	8	4.1%	47	24.2%	17	8.8%	17	8.8%	194
7	21	6.9%	18	5.9%	44	14.5%	166	54.6%	7	2.3%	48	15.8%	304
11	20	5.4%	9	2.5%	43	11.7%	249	67.8%	9	2.5%	37	10.1%	367
Radio-ulna	120	7.4%	77	4.7%	625	38.5%	717	44.1%	29	1.8%	57	3.5%	1625
2	66	36.7%	39	21.7%	9	5.0%	33	18.3%	7	3.9%	26	14.4%	180
9	39	7.8%	17	3.4%	141	28.0%	275	54.7%	12	2.4%	19	3.8%	503
12	15	1.6%	21	2.2%	475	50.4%	409	43.4%	10	1.1%	12	1.3%	942
Tibia	174	10.3%	86	5.1%	411	24.4%	943	55.9%	47	2.8%	24	1.4%	1687
4	93	33.2%	42	15.0%	26	9.3%	93	33.2%	19	6.8%	5	1.8%	280
6	23	3.1%	31	4.2%	224	30.4%	435	58.9%	14	1.9%	11	1.5%	738
10	58	8.7%	13	1.9%	161	24.1%	415	62.0%	14	2.1%	8	1.2%	669
Total	459	9.2%	282	5.7%	1172	23.5%	2696	54.1%	131	2.6%	245	4.9%	4987

Table 6: Type of percussion marks by experimenter and by element on NISP (Total PM: Percussion marks total).

The crushing marks were often situated close to the articular portions (Figure 4 and 5). We documented some crushing marks on the medial diaphysis of the humeri and the radio-ulnas and the tibias of volunteer n°4. Furthermore, we recorded most of the percussion marks on the diaphysis; only the pits and grooves were located on the articular portions. It was difficult to

observe a concentrated area of percussion marks on the template on which we drew the marks. We merged all the percussion marks derived from the 10 bone elements into a single series and performed an optimized hot spot analysis to evaluate high concentration zones of percussion marks (Figure 6, 8, 10, 12). For each long bone series, we tested all the percussion marks together, apart from percussion marks causing a fracture ("CNA") and the others (pits and grooves) (Figure 7, 9, 11, 13).

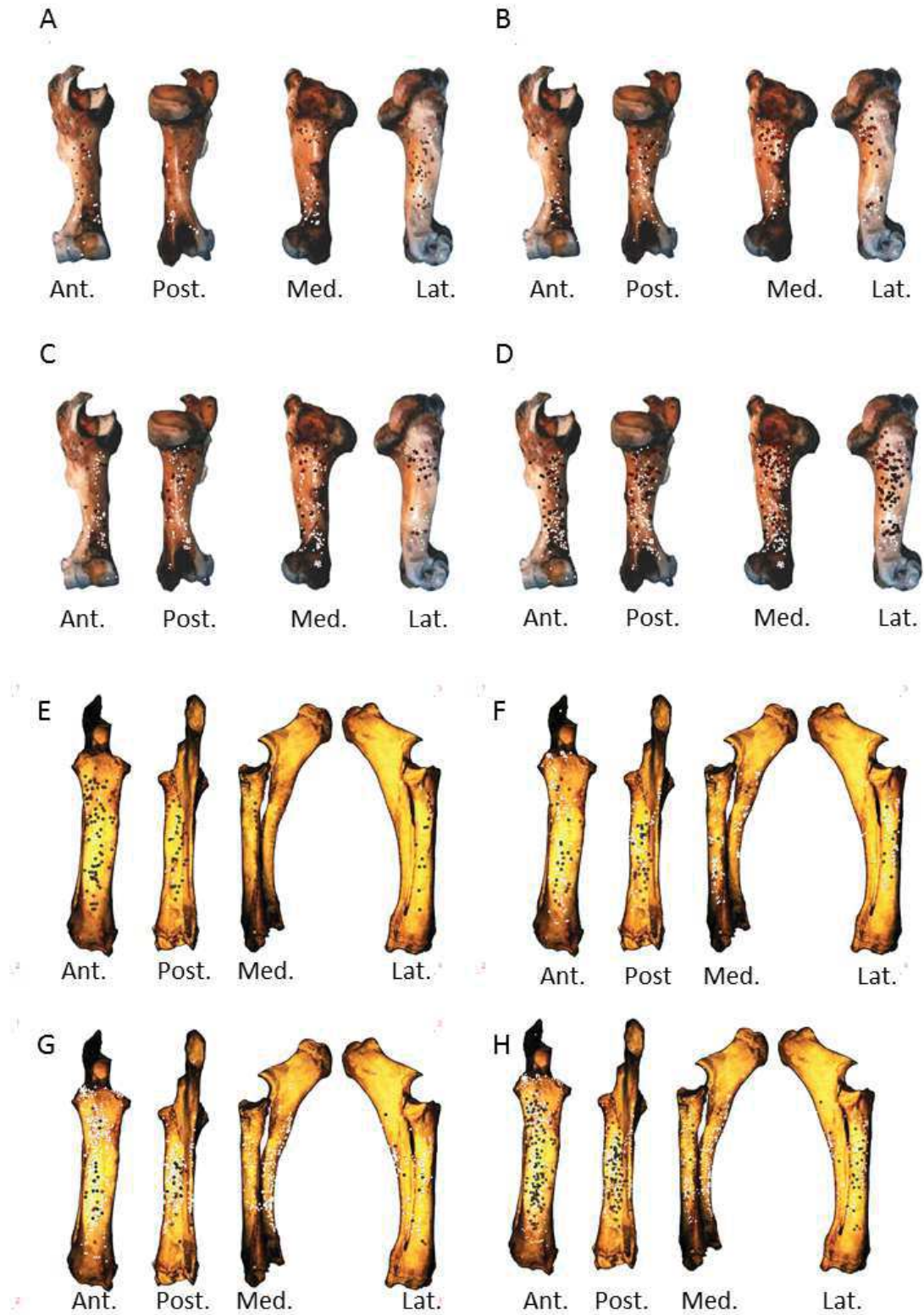


Figure 4 : Distribution of percussion marks along the humerus and the radio-ulnas divided by type of percussion mark (red star: crushing marks, white triangle: pits and grooves and grey circle: notches and adhering flakes); A- Individual n°1; B- Individual n°7; C- Individual n°11; D- Merged humerus series; F- Individual n°2; G- Individual n°9; H- Individual n°12; I- Merged radio-ulnas series.

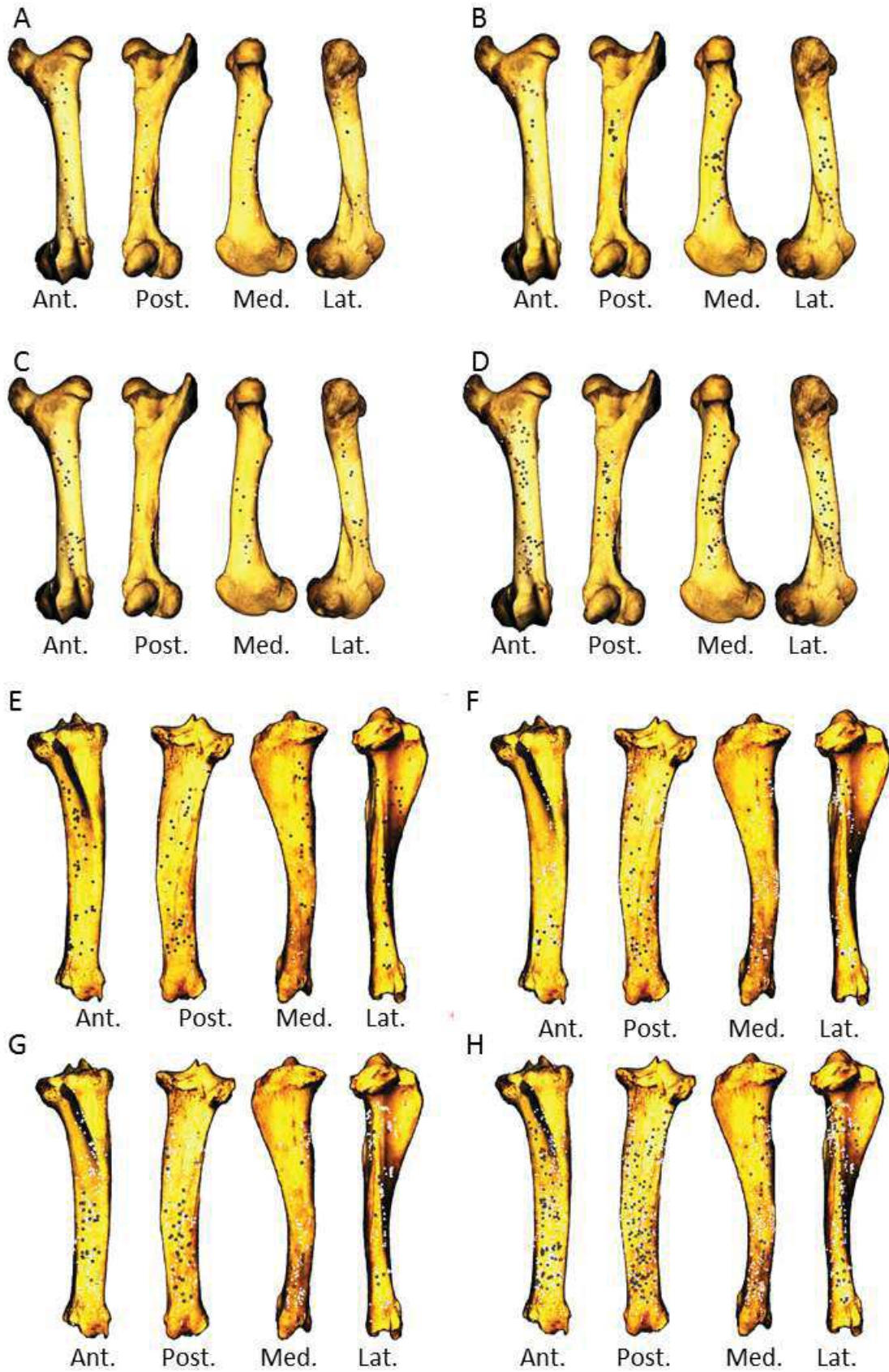


Figure 5: Distribution of percussion marks along the femurs and tibiae divided by type of percussion mark (red star: crushing marks, white triangle: pits and grooves and grey circle: notches and adhering flakes); A- Individual n°3; B- Individual n°5; C- Individual n°7; D- Merged femurs series; G- Individual n°4; H- Individual n°6; I- Individual n°10; J- Merged tibiae series.

The analyses taking into consideration all the percussion marks generally highlighted cold spots on the articular portions, for all the studied long bones. Conversely, hot spots were generally highlighted on shaft portions. In particular, most of the time the ulna was a cold spot for all the series of radio-ulnas. Likewise, for almost all the series, the tibia crest was a cold spot. The majority of the cold spots were observed on proximal and distal articular portions with the exception of the proximal portion of the radius in the “CNA” analyses) and on the tibia crest and ulnas (Figure 4 and 5).

The spatial analyses show that the majority of the high confidence hot spot zones for the humerus series were on the medial and lateral sides (Figure 6). Experimenter n°11 was an exception with hot spot areas on portion 4 of the posterior and anterior sides. The merged humerus series showed four high confidence hot spot zones on the medial and lateral sides. The hot spot zone on the medial side of portion 2 is the largest, and the one on the lateral side of portion 2 is the smallest. The last ones are located on portion 4 (Figure 6). When we consider the two types of percussion marks, we observe some differences in the location of the high confidence hot spot zone. The “CNA” were on the lateral and medial sides of portion 2, the pits and grooves were also on the medial side of portion 2, but also on all sides of portion 4 (Figure 7).

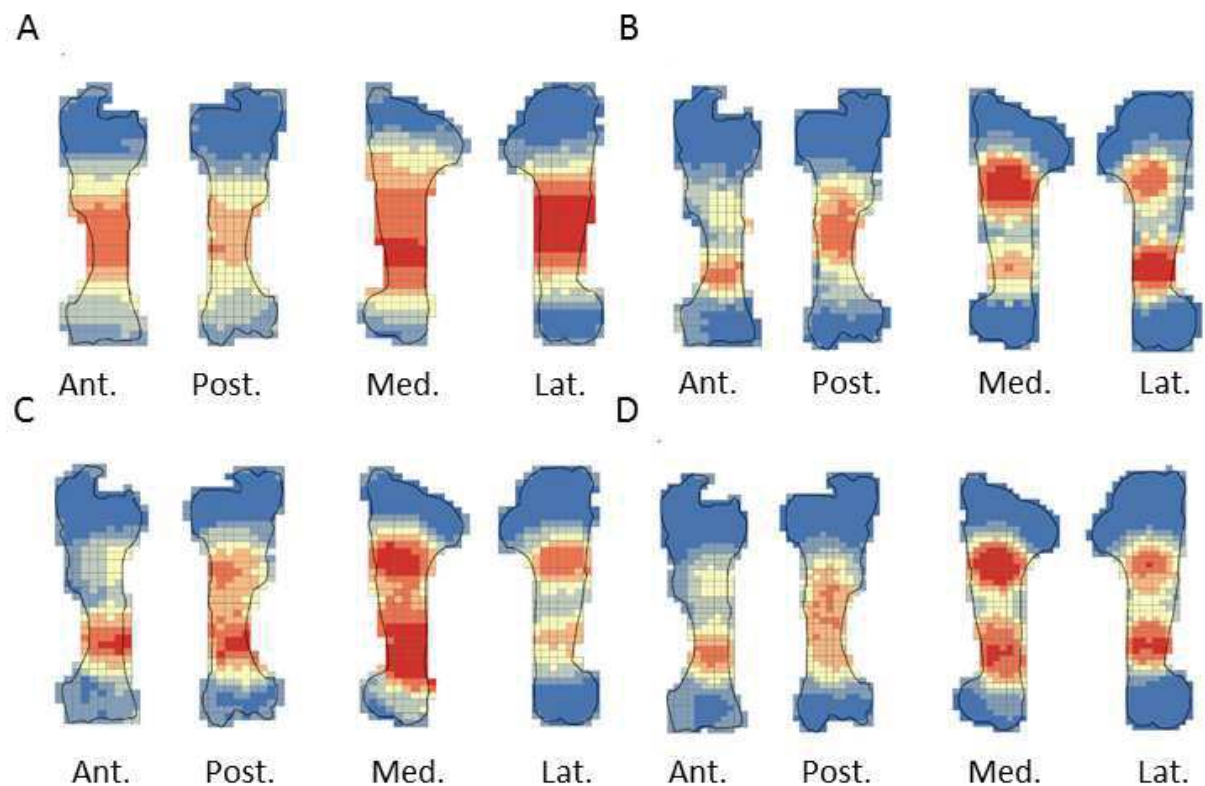


Figure 6: Optimized Hot spot analysis of combined percussion marks from the humerus in each series: A- Individual n°1; B- Individual n°7; C- Individual n°11; D- Merged humerus series

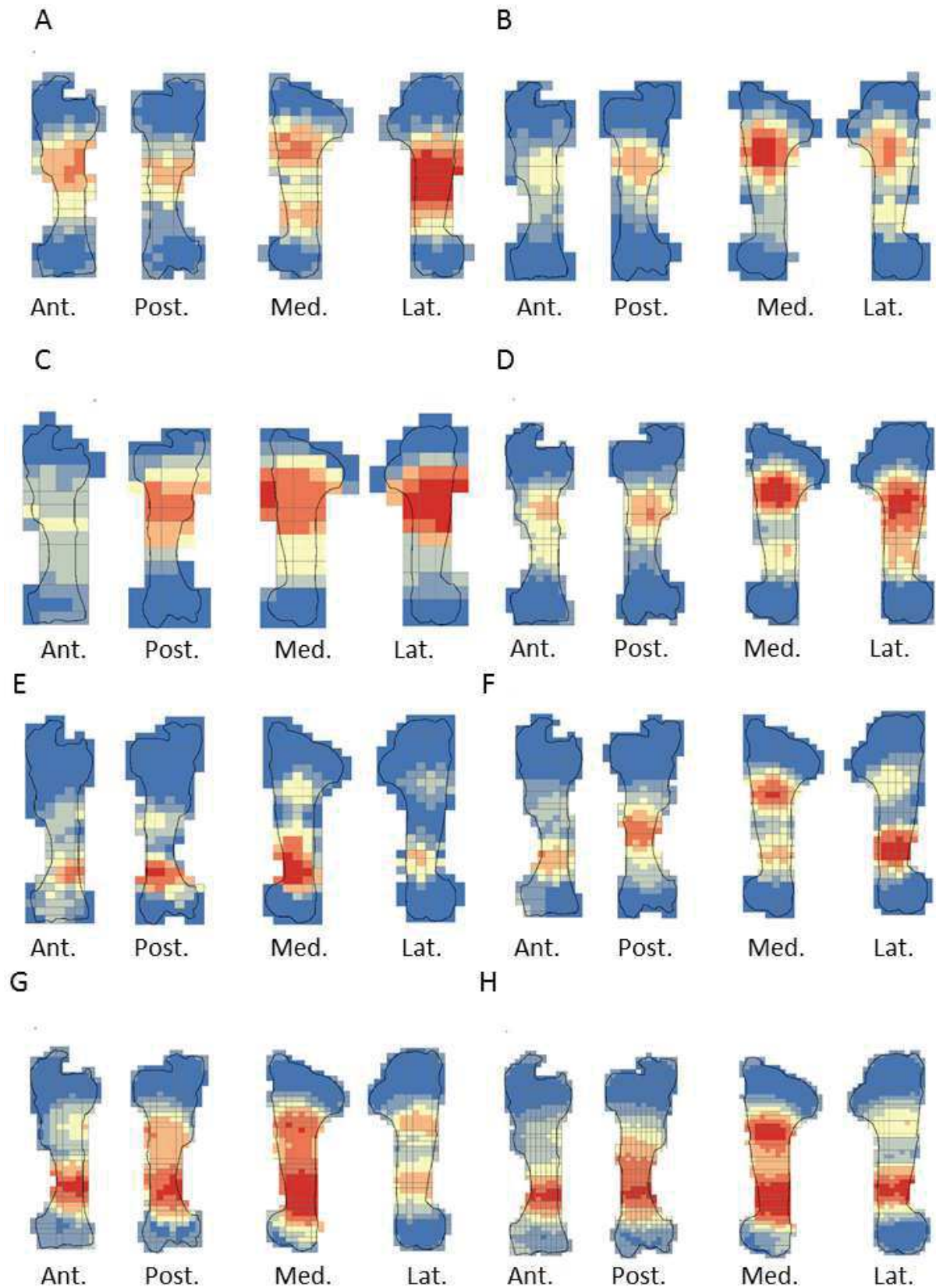


Figure 7: Optimized Hot spot analysis of combined percussion marks from the humerus in each series: A-E- Individual n°1; B-F- Individual n°5; C-G- Individual n°8; D-H- Merged humerus series; A, B, C and D: "CNA" Percussion marks and E, F, G and H: pits and grooves

For the radio-ulna series, we observed hot spot areas on the anterior and posterior sides for all the individuals (Figure 8). Individual n°9 was the only one who frequently hit portion 3-4 on the medial side. The analysis of the combined radius-ulna series highlighted a high confidence hot spot zone on the posterior side of diaphysis portions 2 and 3. This result reflected the general tendencies observed for all volunteers. The analysis defined a reduced area, portion 2 on the anterior side, as a hot spot zone, which was influenced by individual n°9. The results of the analysis showed that the high confidence hot spot zone for the merged radio-ulna was on portion 3 of the posterior side, and on the anterior side portion 3-4 for “CNA” marks only (Figure 9).

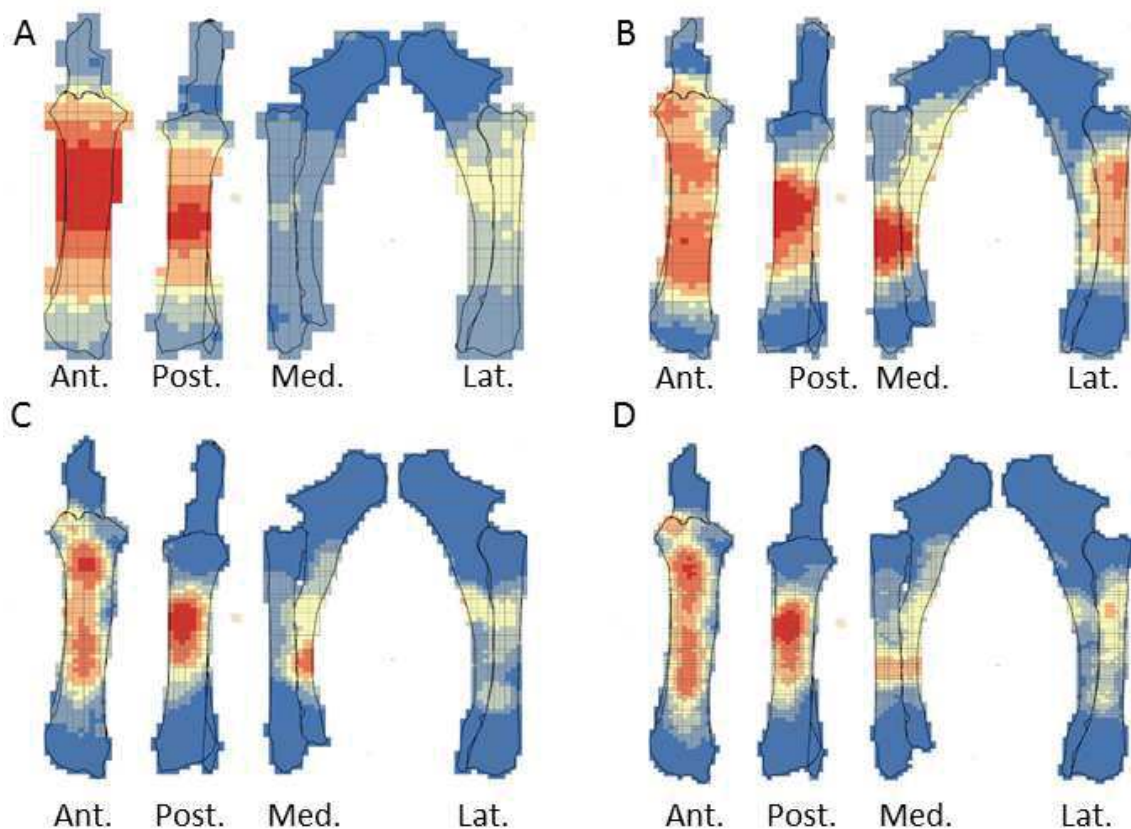


Figure 8: Optimized Hot spot analysis of combined percussion marks from the radio-ulnas in each series: A- Individual n°2; B- Individual n°9; C- Individual n°12; D- Merged radio-ulnas series

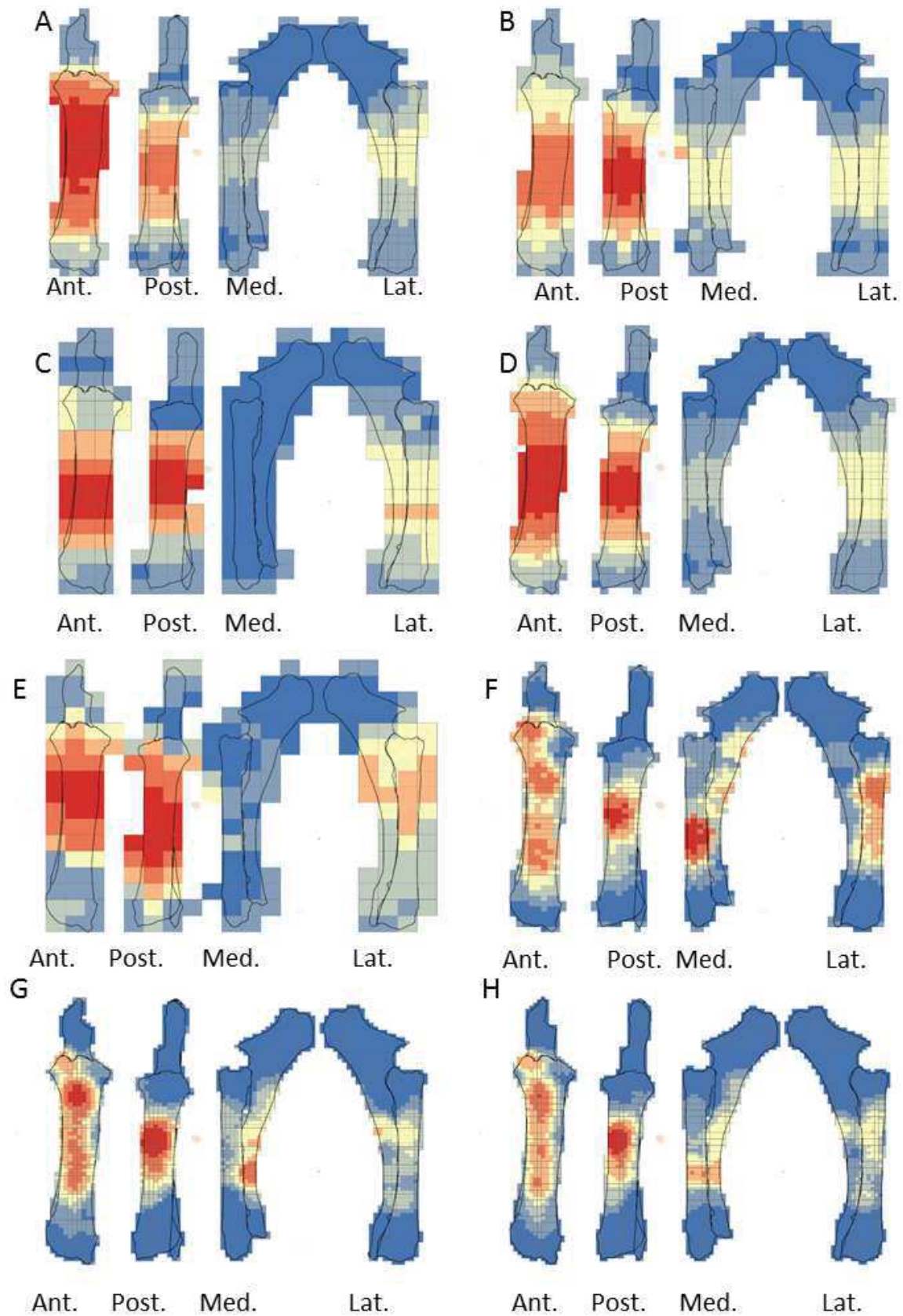


Figure 9: Optimized Hot spot analysis of combined percussion marks from the radio-ulnas in each series: A-E- Individual n°2; B-F- Individual n°9; C-G- Individual n°11; D-H- Merged radio-ulnas series; A, B, C and D: "CNA" Percussion marks and E, F, G and H: pits and grooves

The spatial analyses of the femur series show diversified distribution of the hot spot zones along the diaphysis, depending on the experimenter (Figure 10). For the three series, all sides were a hot spot area at least once, reflecting high inter-individual variability. However, the spatial analysis of the merged femur series shows three confident hot spot zones, quite similar to individual n°8, on portions 2 and 4 on the anterior side, and on portions 3 and 4 on the medial side. High confidence hot spot zones for both percussion mark types are more numerous and dispersed on the merged femur than on the other bones (Figure 11).

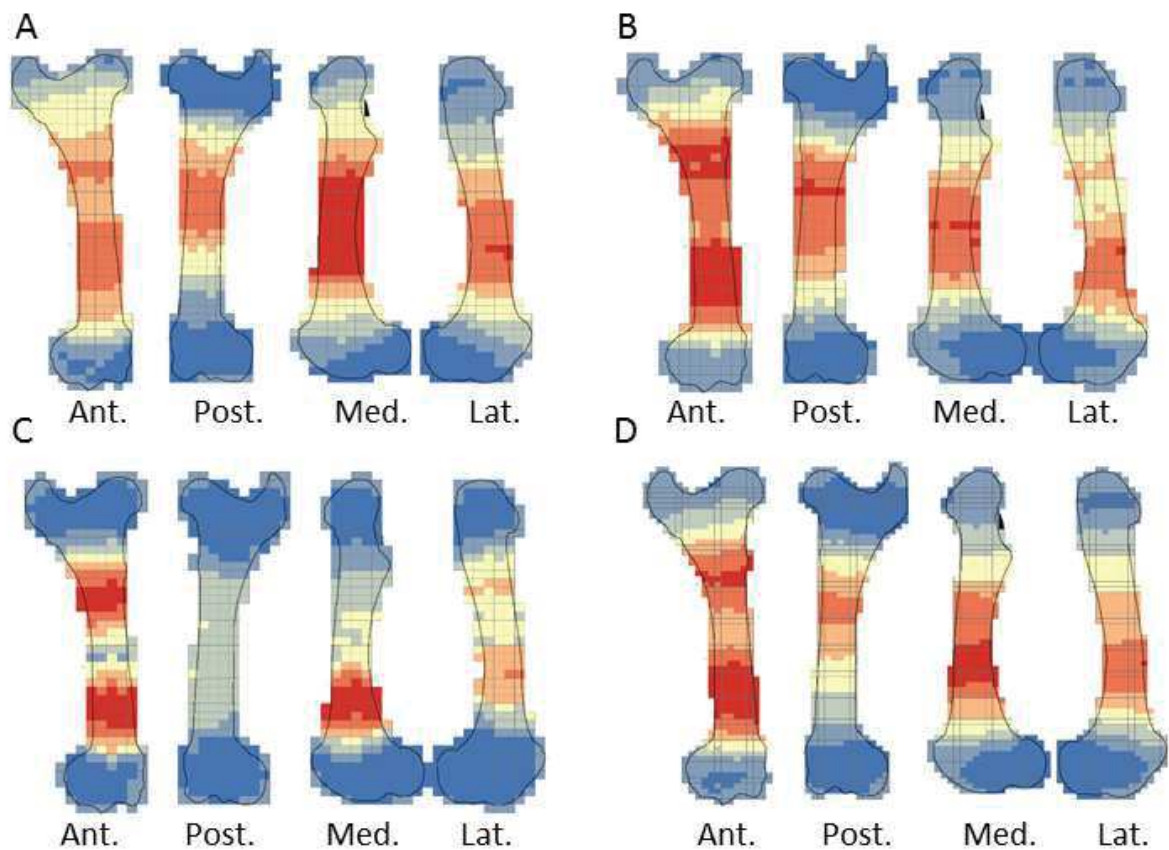


Figure 10 Optimized Hot spot analysis of combined percussion marks from the femurs in each series: A- Individual n°3; B- Individual n°5; C- Individual n°7; D- Merged femurs series

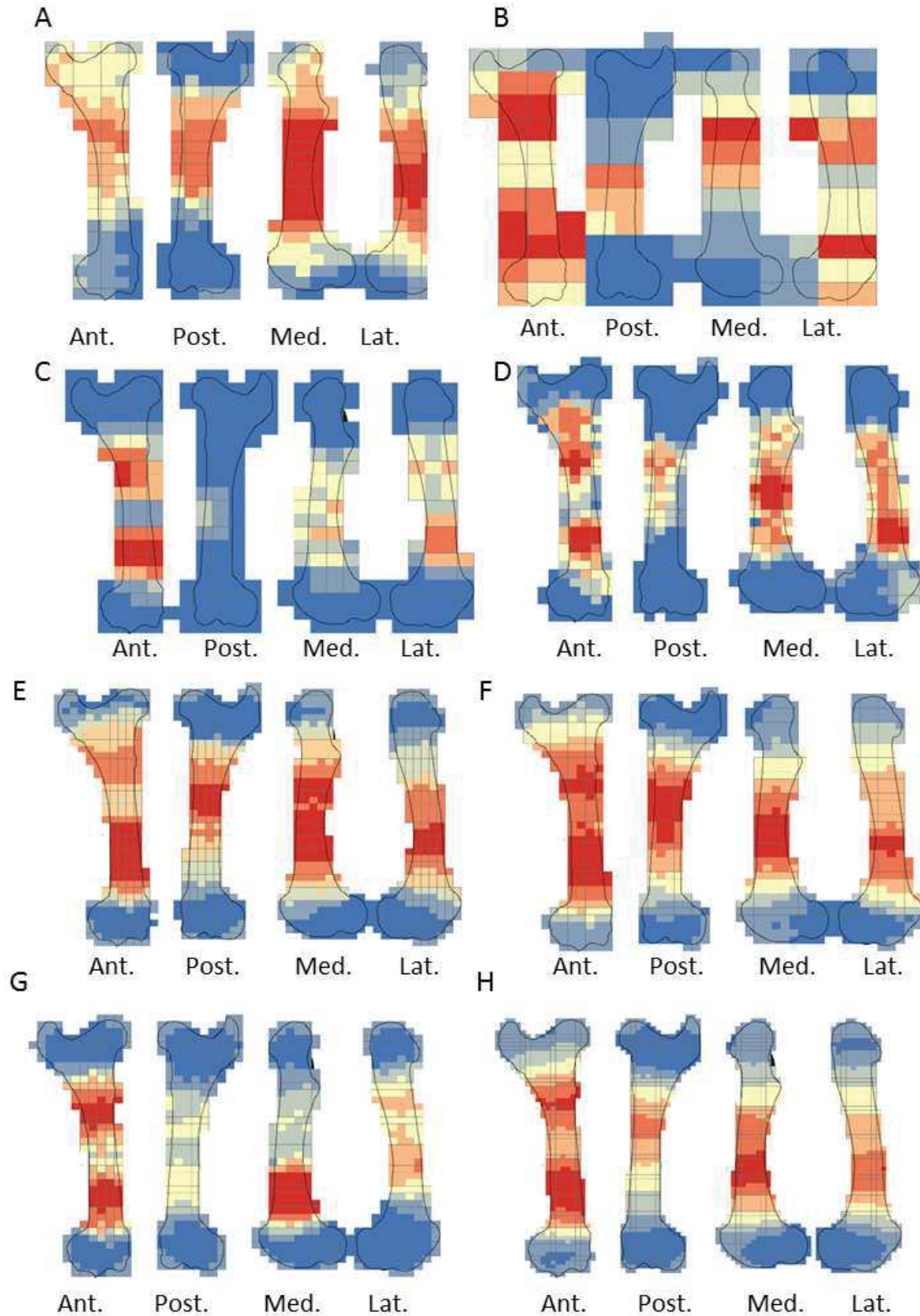


Figure 11: Optimized Hot spot analysis of combined percussion marks from the femurs in each series: A-E- Individual n°3; B-F- Individual n°5; C-G- Individual n°7; D-H- Merged femurs series; A, B, C and D: "CNA" Percussion marks and E, F, G and H: pits and grooves.

For the tibia series, we observed high confidence hot spot zones on anterior and posterior sides for each volunteer, in particular on portions 3 and 4 (Figure 12). The lateral side highlighted hot spot areas for individuals n°6 and n°10, especially on portion 2. The merged tibia series reflects the dispersion of the high confidence hot spot zones observed for each series. The spatial analyses showed six hot spot zones, two of which very limited in size. However, the “CNA” area of high confidence hot spot was only on the posterior side of portions 3 and 4. Zones with pits and grooves were numerous, distributed on the diaphysis of the lateral, anterior and posterior sides (Figure 13).

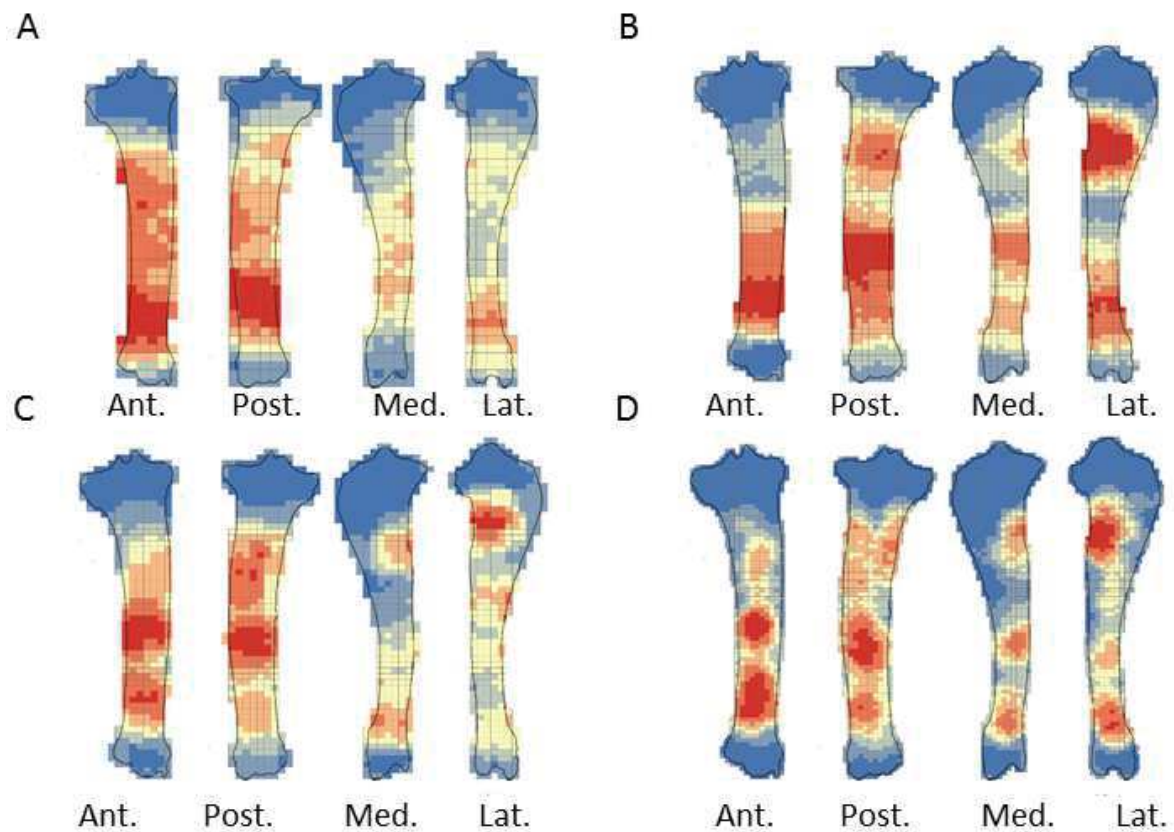


Figure 12: Optimized Hot spot analysis of combined percussion marks from the tibias in each series: A- Individual n°4; B- individual n°6; C- Individual n°10; D- Merged tibias series

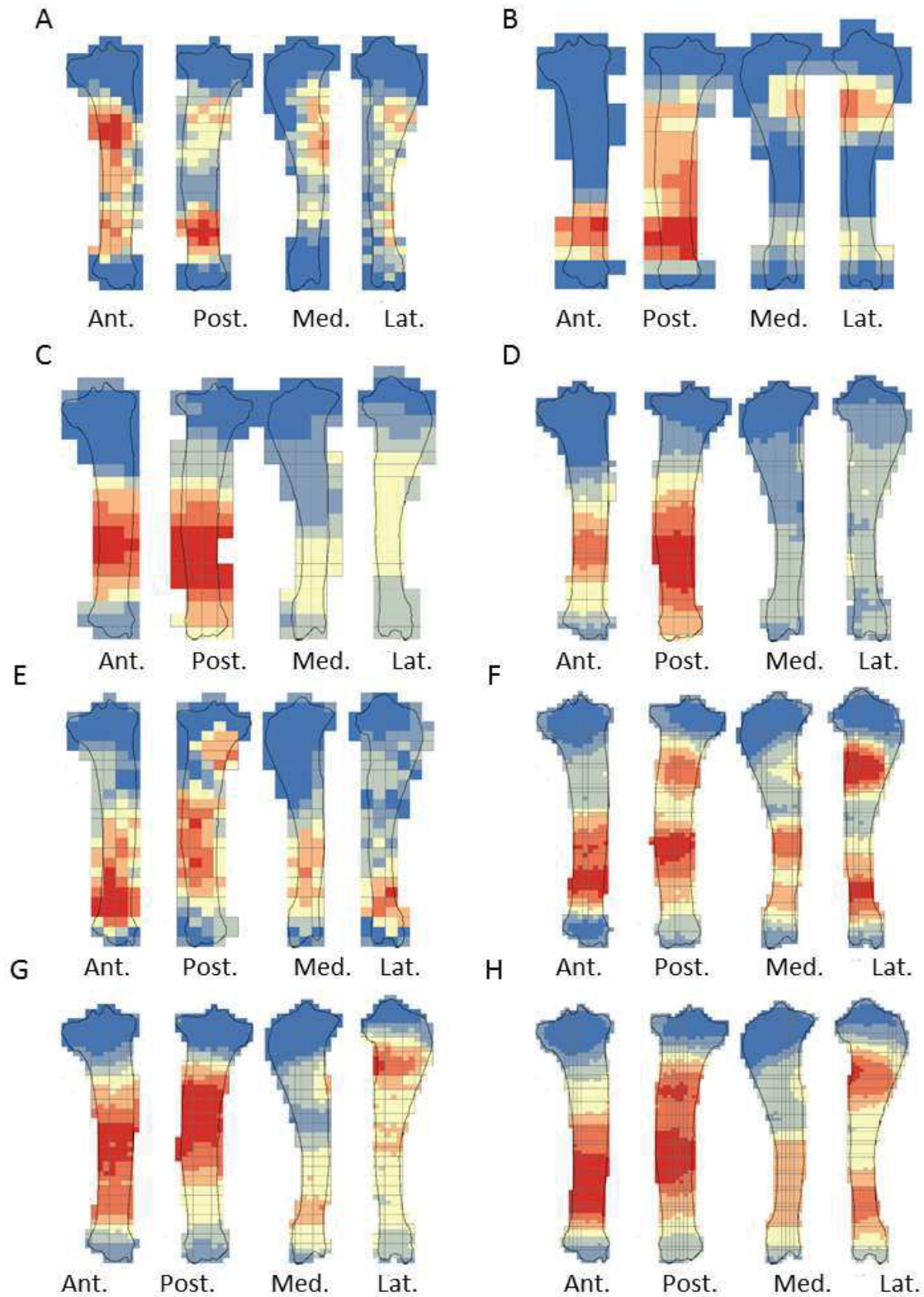


Figure 13: Optimized Hot spot analysis of combined percussion marks from the tibias in each series: A-E- Individual n°4; B-F- Individual n°6; C-G- Individual n°10; D-H- Merged tibias series; A, B, C and D: "CNA" Percussion marks and E, F, G and H: pits and grooves.

Discussion

The most significant information highlighted by our experiments is related to the variability observed during the breakage process and that observed among the bone elements produced during experimentation. Indeed, some individual behavioural tendencies emerge during the breakage process, as well as patterns in the production and distribution of percussion marks. Our results also brought to light the influence of long bone morphology in an intuitiveness context.

How do individual gesture alternatives and bone elements influence breakage methods?

Some volunteers applied reduced force when they hit the bones, especially during the first attempts. Initially, experimenters tested the resistance of the bones and some were afraid of hurting themselves. In these cases, they hit the bones with less force. Likewise, at the end of the experiment, tiredness resulted in a reduction of the force applied. After the activity, most of the experimenters had a shaking hand, and all the volunteers had aches and pains the following days. This shows that marrow extraction requires a good physical condition and/or practice and/or good technical skill. During the activity, some volunteers progressed or developed habits or a routine. However, they did not seem to become more efficient at optimally breaking bone to extract the maximum quantity of marrow. In addition, during the experiment, the volunteers mentioned inter-element differences, whereby some bones were easier to break than others, irrespective of the experience acquired or the degree of exhaustion. Moreover, it is important to note that sometimes the hammerstone slipped on the cortical surface or slipped out of the experimenter's hand. This happened especially when the hammerstone and hands were covered in grease after several tries. When an individual broke several bones, he/she had to clean the tools or his/her hands to pursue marrow extraction.

One of the most significant results of our experiment was the variability of individual behaviour during marrow recovery. One volunteer adopted an unexpected posture: a cross-legged seated position. However, the observed variability only comprised five positions. In addition to these postural variations, we documented some non-linear behaviour during the experiment. Our experiment showed that non-trained experimenters could change their position at different moments during both the marrow extraction from one bone and throughout the ten bone series. However, the majority of the experimenters kept the same position or developed some kind of habit or routine in their practice. This routine concerned the individual and bone position and the way of grasping the bone and percussor. The auto-learning developed by experimenters to be as efficient as possible involved their position and their way of grasping the bone and percussor. The position influences the amplitude of the gestures, the force involved in breakage and the location of the blows. The standing position was only selected by women, and

not by all of them. Sex did not influence the choice of posture or position of the bone. No link was found between the gender of the experimenter and how consistent they were in their posture choice or in positioning the bone throughout the experiment. Likewise, sex did not seem to influence the way the percussor was grasped or the use of an anvil. These results could provide some evidence regarding the organization of butchery task distribution during the Palaeolithic. We noted that the posture adopted by individuals did not vary in relation to the skeletal element. However, the type of long bones seemed to affect practices and gestures, in particular for tibias and radio-ulnas. This observation could be related to the high number of blows applied to these two bone types by novice experimenters.

Although experimenters proceeded differently depending on the elements, we noticed some divergences in our results, in particular between radio-ulnas and tibias. The experimenters who broke the radio-ulna series had a very low yield in relation to the number of blows. On the whole, the opposite is true for the tibia series, for which individuals had a high yield. Thus, volunteers who broke radio-ulnas found the activity quite difficult and considered the marrow to be of relatively poor quality. On the other hand, the volunteers who broke tibias found the activity quite easy and the extracted marrow was considered to be of relatively good quality. Furthermore, experimenters used two hands at least once for breaking radio-ulnas, but never for tibias. The use of both hands to grasp the pebble was an expression of the difficulty felt by the individuals breaking radio-ulnas. Regarding the NSP produced for both these elements, we recorded the highest number of blows and the lowest NSP for the radio-ulnas and the exact opposite for the tibias of our sample. This was why we observed a high number of pits and the lowest number of "CNA" percussion marks on radio-ulnas. Contrary to the tibia, the breakage of a radio-ulna of an animal such as a cow requires some mastery. Numerous studies have highlighted differences between the volumes of the medullar cavity of these two long bones. Tibias and femurs comprise large medullary cavities. On the other hand, medullary cavities are smaller for radio-ulnas and humeri and thus contain a lesser quantity of yellow marrow (Binford, 1981, 1978; Jones and Metcalfe, 1988). Therefore, the EFI (Efficiency Index) highlighted differences between the energy spent by counting the blows and the quantity of marrow extracted, in part because of the difference in volume between the radio-ulna and tibia series. However, medullary cavity volume alone cannot account for all the differences observed between bones. In terms of density, tibias and radiuses show the highest diaphysis density of all the long bones used in our experiment (Lam et al., 1999; Lyman, 1994). However, they seem to react differently to blows. This difference was highlighted by the PCA, showing an opposition between the radio-ulna and the tibia series regarding the NSP, the Efficiency Index and the number of percussion marks.

What correlation can be made between blows and percussion marks?

Various researchers have stressed that the aim of mastering percussion breakage was to reduce the number of blows required to remove all the marrow from the medullary cavity (Capaldo and Blumenschine, 1994; Galán et al., 2009; Moclán and Domínguez-Rodrigo, 2018). For this reason, it was expected that novice experimenters would average more blows than experts. Indeed, we noted a high number of blows, ranging from 6-279, with an average of 52, for the entire bone experiment. If we compare our experiment with previous works, we observe a huge difference between the average number and range of blows (Table 7). The average number of blows by volunteers in our experiment was higher than the maximum in other studies. In particular, for their first tries, two individuals hit the bones more than 200 times. Besides, none of the experimenters stopped hitting the bones after the first fracture. The presence of the periosteum on the bones was not sufficient to explain the very high number of recorded blows. Indeed, during some experiments quoted in Table 7, the periosteum was not removed (Martin, 1910; Pickering and Egeland, 2006; Rovira Formento, 2010). Novice volunteers tried to break the element further in order to recover the maximum amount of marrow. The weighing of the marrow after each attempt motivated some of them. At the individual scale, we observed some increase or decrease in the number of blows at the beginning and the end of the experiments, but overall, we did not highlight significant progress for all the experimenters or a particular element. The only exception was the humerus, for which the number of blows decreased for all the volunteers. The number of blows and the experimenters' decision to pursue breakage after the first fracture can increase the NSP. Intensive breakage can reflect a high number of blows in order to access the yellow marrow. In addition, we observed the quasi-systematic conservation of the epiphyses in their entirety. Indeed, it is not necessary to break the articular portions for the extraction of yellow marrow only.

References	Species	Element	Range of number of blows	Mean of number of blows	NSP/NME=MeanNSP
(Rovira Formento, 2010)	Horse	Femurs	1-27	8.8	-
(Galán et al., 2009)	Cow	Humerus Femurs Radio-ulna	- - -	- - -	145/22=6.5
(Pickering and Egeland, 2006)	White deer	Radius Humerus	2-15 1-4	6 2	811/38=21.3 472/36=13.1
(Thiébaud et al., 2007)	Cow	Femurs	1-8	3.5	189/13=14.53
(De la Torre et al., 2013)	Cow	Limb bones	-	20	-
(Martin, 1910)	Horse	Femurs Tibia	1-3 3	2 3	-

Table 7: Listing of different experiment of bone breakage for marrow extraction and comparing data.

Interestingly, the number of blows is not correlated with the number of percussion marks. Comparing the two values, we noted that for two-thirds of the individual bone elements, the number of blows is higher than the number of percussion marks and more surprisingly, for one-third of the bone elements, the number of percussion marks is higher than the number of blows. For one experimenter per bone element (humerus: n°7, radio-ulna: n°12, femur: n°8 and tibia: n°10), the number of blows was inferior to the number of percussion marks.

In most cases (more than 95%), the number of pits and grooves or “CNA” marks was different to the number of hits. In an archaeological context, it can thus be impossible to infer the number of blows from the number of percussion marks. The use of an anvil or the hammerstone could explain the differences recorded between the number of marks and blows. In their experiment, (Pickering and Egeland, 2006) also observed a majority of pits among the recorded percussion marks. They concluded that most of these pits were produced by the counterblow of the anvil. In our experiment, pits were generally more numerous than the other marks (67 %). Thus, pits and grooves result from the rebound effect caused by the hammerstone or by the anvil due to the counterblow. In this last case, the counterblow is not a mark; but rather the result of the rebound effect of the bone on the anvil. The marks due to counterblows include pits, microstriations, outer conchoidal scars or notches (e.g.,: Boulestin, 1999; Capaldo and

Blumenschine, 1994; Gifford-Gonzalez, 2018; Johnson, 1985; Lyman, 1994; Outram, 2002), located on the opposite side to the blow. Due to the multiplicity of traces and the overlapping of the traces produced by the hammerstone or when the long bone is batted against a hard surface, it is difficult to discriminate blow marks from counterblow marks. In addition, we recorded some triangular pits and grooves even though experimenters only used non-retouched pebbles. These marks, characterized by straight and sharp edges, could be the product of the rebound effect from the anvil. Therefore, the use of an anvil could create supplementary marks during the blow. Two volunteers (n°8 and 11) did not use the anvil at all, but simply laid the bones on the ground. Nonetheless, some triangular pits and grooves were identified (around 10 %). However, we sometimes recorded more marks than blows. Thus, the counterblow is not the sole explanation for the difference between the number of blows and the number of percussion marks. It is possible that the shape of the hammerstone, the impact with the ground or the collision of bones between them during the activity created several pits. More than one-quarter of the recorded pits were very small and superficial, with a diameter of 10 mm or less (28%). In an archaeological context, the different taphonomical processes, such as trampling, for example (Domínguez-Rodrigo et al., 2010), can erase these pits or produce others. For the remaining two-thirds of the broken elements, we recorded a lower number of percussion marks than blows. In our protocol, the periosteum was never removed. The presence of the periosteum, which absorbed some of the force of the blows, could partly explain this difference.

Percussion marks distribution

The areas where the least percussion marks were observed, apart from the articular portions, were the anterior crest of the tibia and the diaphysis of the ulna. The distribution of percussion marks showed that novice experimenters avoided shape constraints, such as bone protuberances. They seemed to prefer relatively flat areas. Thus, the spatial analyses for tibias and radio-ulnas highlighted significant hot spot zones for the merged series, where bone shape was the flattest. Furthermore, for the “CNA” marks, a single hot spot area was most impacted on the tibias. This area was located on the posterior side of the distal diaphysis. It was one of the flattest and smoothest zones of the tibias with no muscular lines. Moreover, the distal diaphysis is the least dense portion of the tibia (index density = 44) (Lyman, 1994). Regarding the “CNA” marks, two specific high confidence hot spot zones were identified on the radio-ulnas. They were located on relatively flat and easily accessible areas to blows. The first one is situated on the anterior side of the medial shaft, which is relatively flat considering the globally very arched shape of the radio-ulna. The radio-ulna section in this area is flattened compared with portions 3 and 4, which present a semi-lunar crescent shape. When the bone was placed on a small anvil, one of

the best ways to stabilize the radio-ulna was to place the medial shaft on the posterior side. Thus, the anterior side was exposed and very accessible. The other hot spot area was on the exact opposite side because, on the ground, it was easier to place the bone on the anterior side to avoid interference from the ulna. In addition, when the radio-ulna was positioned on the anterior side, this area was located at the inflexion point of the bone curve and was the most accessible to hit. Furthermore, these areas were located on portions 2 and 3, which are the densest part of the radius (marrow index = 0.56 & 0.62).

Unlike zeugopods, the diaphyseal section of humeri and femurs is rather cylindrical. Their diaphyses are relatively straight in comparison to the radio-ulna. The articular portion shows important differences in terms of stability. The humerus is more stable on its lateral and medial sides whereas the femur is relatively stable on all sides. Indeed, the very rounded shape of the humerus head causes instability when placed on its posterior side. This is why the distribution of percussion marks, highlighted by the hot spot analyses, is concentrated on the lateral and medial sides. Pit and groove marks are generally distributed on the distal part of the bone. This part of the humerus diaphysis is denser than the others (density index = 0.48). Conversely, the hot spot area of "CNA" marks is only located on the proximal shaft portion, in the least dense part of the bone (index density = 0.25). These "CNA" marks represent one of the most numerous hot spot zones. In addition, these hot spot areas were similar for the three merged spatial analyses of the femurs (all percussion marks, "CNA" marks and pits and groove marks). All the diaphysis portions were hot spot zones at least once, independently of density variability.

Thus, percussion mark location is influenced by the morphological constraints of bones, in particular for the radio-ulna, the tibia and the humerus, in an intuitive context. Volunteers were faced with bone marrow extraction for the first time and were highly influenced by shape constraints. These constraints were so strong that volunteers continued hitting these zones after many attempts, as bone stability and the accessibility of these areas facilitated breakage and therefore marrow recovery. Nonetheless, the absence of morphological constraints seems to highlight novice choices. Therefore, based on the results of our analyses, in an intuitive context, femurs seem to be the bones for which individual variability was highest.

Archaeological, experimental and ethnographical data comparisons: some convergences

Binford (1981) described the practices and gestures of the Nunamiut in order to infer past hunter-gatherer behaviour from archaeological assemblages. His observations describe systematic breakage, hitting the same bone portions each time. Moreover, in the same way as

experiments, ethnographical studies highlight wide-ranging variables, which are hardly accessible in archaeological contexts.

We highlighted the existence of a preferential pattern for the intuitive breakage of long bones, using the spatial analysis of the location of percussion marks on radio-ulnas, tibias and humeri. Archaeological and ethnographical studies focusing on the distribution of percussion marks along long bone diaphyses have revealed the existence of preferentially impacted areas (Binford, 1981; Blasco et al., 2013; Masset et al., 2016; Moclán and Domínguez-Rodrigo, 2018; Vettese et al., 2017). The comparison between these results and ours underlines the influence of bone shape on some systematic practices of extant and past hunter-gatherers (Figure 14). For radio-ulnas, archaeologists record percussion marks on the anterior side, in particular in the faunal assemblages of level XVIIc of Bolomor Cave (Blasco et al., 2013) and at the Abri du Maras layer 4.1 (Vettese et al., 2017), where some tendencies were observed (Middle Palaeolithic), Combe Saunière and Cuzoul de Vers (Castel, 1999) and the “upper unit” of Saint-Germain-la-Rivière (Costamagno, 1999; Masset et al., 2016) and the Rond du Barry (Upper Palaeolithic), and also among the extant Nunamiut (Binford, 1981). The areas highlighted by hot spot analyses were similar to the areas of percussion mark concentrations in these comparative examples. These faunal assemblages represent practically all the Palaeolithic sites for which percussion mark distribution has been studied. The aforementioned faunal assemblages are dominated by different species: reindeer, saiga antelope, ibex, red deer or larger-sized ungulates, like horse or bison, and in our experiment, cow. This comparison suggests that the high shape constraints of the radio-ulnas strongly influenced the distribution of percussion marks on whole long bone remains in an archaeological level independently of ungulate size. Furthermore, for ungulates, the fact that the radius is merged with the ulna constrains the morphological shape of the bones. However, level IV of Bolomor Cave and the “lower unit” of Saint-Germain-la-Rivière showed different patterns on the lateral side for the former site and both lateral and medial sides for the latter (Figure 14).

For the humerus, the distribution of percussion marks was quite similar to our observations. Almost all the sites presented in the work of Masset et al. (2016) reveal a pattern on the medial and/or lateral sides, with the sole exception of Bolomor Cave level IV. Compared to the other sites, we noted variability in the exact area impacted by percussion marks, but we observed a preference for portion 4 in the majority of the assemblages. A minority of the studied tibia series showed a systematic pattern or strong tendencies. The posterior sides displayed the most areas of percussion mark concentration. Finally, most of the femur series from the archaeological sites studied do not seem to show systematic distribution, with the exception of

level VI of Bolomor, which indicates two preferentially impacted zones, and the Abri du Maras, where one area was more impacted than the other. We observe similarities with the Nunamiut for the anterior side.

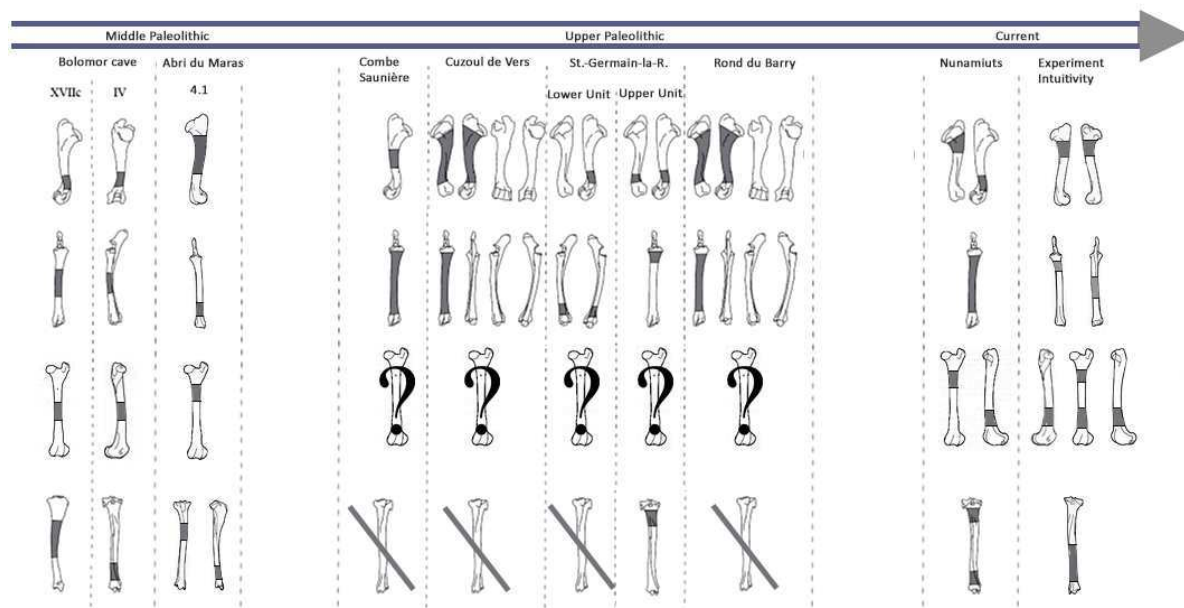


Figure 14: Location of percussion marks (grey areas) for the humerus, radio-ulna, femur, and tibia for sites from the Middle Paleolithic: Bolomor cave (ungulates: Blasco et al., 2013b.) and Abri du Maras (middle sized-ungulates: Vettese et al. 2017); the Upper Paleolithic: Combe Saunière (reindeer, Solutrean: Castel, 1999), Cuzoul de Vers (reindeer, Badegoulian: Castel, 1999), Saint-Germain-la-Rivière, Lower Unit (saiga antelope, Lower Magdalenian: Costamagno, 1999) and Upper Unit (saiga antelope: Masset et al. 2016), Rond du Barry (ibex, Upper Magdalenian: Costamagno, 1999), for these series the data regarding the femurs were missing and most of the tibias did not present higher tendencies; Current: Nunamiut people of Alaska (reindeer: Binford, 1981 and the results of our experiment regarding the CNA).

Conclusion

For the purposes of testing intuitiveness in bone breakage, we experimentally tested the influence of individual behaviour and long bone morphology on percussion mark location. We observed a high variability of gestures during the breakage process. Most of the volunteers developed their own routine. This routine included several positions and different techniques, involving variability in the applied force and different bone element responses. Nevertheless, our results highlight similarities in percussion mark distribution despite the specificity of each experimenter, for most of the long bones studied here. Indeed, one of the most important results is the identification of specific hot spot areas, regardless of the variability of experimenters' behaviour during the breakage process. These similarities can be considered as intuitive patterns.

The location of percussion marks is influenced by numerous variables depending on: the experimenters' behaviour and skills, the techniques employed, the location of the blows, the morphology of the skeletal element and bone position during breakage. Nevertheless, our results

highlighted the predominance of two main factors in an intuitive context: long bone morphology for the humerus, radio-ulna and tibia and experimenters' behaviour for the femur.

From a different perspective, we have shown that bone response can be very different in an intuitive context, notably for the radio-ulna and the tibia. These differences can be observed at almost all the different levels of the analysed data: volunteer behaviour or perception, marrow quality and quantity, number of blows and remains produced and type of percussion marks recorded. These results highlight the diametrically opposed differences between tibias and radio-ulnas in an intuitive context.

Our results shed new light on the importance of gestures in the breakage process. It could prove interesting to model these results and evaluate their amplitude and the force involved. Numerous studies focus on the force required to break long bones but generally concentrate on pressure methods. Consequently, data pertaining to the percussion process are lacking. In addition to measuring the force applied by the blow, it is essential to evaluate the force of the counter-blow caused by different materials, such as stone, bone or wood.

Percussion marks are very instructive in an archaeological context to access past subsistence behaviour. Our results show that percussion traces on fossil bones are only the tip of the iceberg. They only reveal a small window into past bone marrow extraction practices. This experiment highlighted the variability of volunteers' behaviour and the different bone responses during fracturing in order to propose new hypotheses on past butchering practices based on the comparison of the different data analysed in this work.

To conclude, the influence of bone morphology on the distribution of percussion marks in the archaeological record should be taken into account before inferring cultural traditions. It is essential to compare the intuitive patterns highlighted by spatial analysis with the patterns identified in archaeological levels. It could also prove interesting in archaeological contexts to carefully consider percussion mark distribution on the femur as this could be the most instructive bone element, in terms of marrow recovery methods and group specificity.

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III. 6. Du geste au stigmate : apport de l'expérimentation à la caractérisation des impacts de percussion en contexte archéologique

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Du geste au stigmate : apport de l'expérimentation à la caractérisation des impacts de percussion en contexte archéologique

Louis Chevillard

Encadrement : Camille Daujeard, Antony Borel et Delphine Vettese

In a context of study of Neandertalian behaviors, we conducted an experiment of bone fracturing. The goal is to better understand the link between the act performed and the bone changes that percussion can produce. This study is accompanied by an analysis of the long bones of large ungulates at level 4.2 of the Abri du Maras, Ardèche, France. Our study did not reveal any systematization of the fracturing process for this archaeological level, but the results of the experiment allow us to put this conclusion into perspective. The total extraction of the marrow is a process which, it seems, can blur the systematization signal. The experiment also shows that the treatment of a bone element is strongly linked to its morphology. In addition, we have raised the potential importance of cortical removal in the analysis of percussion impacts. Finally, the study extrapolated a particular fracturing technique at the Bolomor site in Spain, highlighting a fracturing that could have been accompanied by complementary treatment of the marrow, such as the heating of long bones.

*Approche techno-culturelle de la fracturation des os longs chez les Néandertaliens (Sud-Ouest de l'Europe, MIS 5-3) :
une systématisation des gestes ?*

III. 6. 1. Résumé long en français

Ce travail de Master 2 résulte d'un stage de recherche mené par L. Chevillard (Parcours, SEP, MNHN). Cette étude a croisé les résultats d'une expérimentation sur la fracturation osseuse avec ceux d'une analyse d'un assemblage de la grande faune fossile issue de la fouille du niveau 4.2 de l'Abri du Maras (Paléolithique moyen). L'objectif était de comprendre et d'interpréter le lien entre le geste effectué et les modifications osseuses produites lors de la percussion. Le protocole expérimental cherchait à tester quelles pouvaient être les variations entre l'emplacement des coups et l'emplacement des marques de percussion sur l'os. Pour cela, de nombreuses variables ont été fixées : un seul individu expérimenté utilisant la même technique et les mêmes outils. Afin de comparer chacun des éléments, le volontaire a réalisé une série pour chaque type d'os. En complément, pour comprendre s'il existait une différence entre les modifications issues de la première fracturation et celles issues de l'extraction de la moelle jaune, l'expérimentation a été divisée en deux phases. La première phase où l'individu stoppait les coups après la première fracturation et la seconde phase, où l'individu tentait d'extraire le maximum de moelle possible après plusieurs coups.

Ce travail a permis de mettre en évidence que le schéma de fracturation se complexifie lorsque la fracturation demande un nombre de coups successifs plus important (phase 2). Durant cette phase 2, l'individu récupère plus de moelle et plus facilement que durant la phase 1. Ce travail a aussi démontré qu'un même geste peut produire différents types de marques de percussion. De plus, son analyse conjointe de l'emplacement des coups et des marques de percussion montre qu'en absence d'enclume la plupart des traces sont localisées aux endroits impactés. Ces conclusions corroborent les résultats précédemment présentés, montrant que la morphologie de l'élément contraint à la fois le nombre de coups mais aussi leur localisation. Par ailleurs, l'expérience des individus impacte ces facteurs. Cependant, s'il est vrai que l'expérience systématise bien les premiers coups avant la première fracturation, la nouvelle forme obtenue une fois l'os fracturé amène l'individu à s'adapter à la nouvelle morphologie de l'os, et ainsi de suite.

La comparaison des résultats de cette expérimentation avec ceux des restes archéologiques a permis d'avancer des hypothèses sur la distribution spatiale des marques de percussion sur les diaphyses osseuses de la grande faune de l'Abri du Maras. Ainsi, la présence de plusieurs zones percutées pourrait signifier un processus d'extraction de la moelle plus poussée, alors que lorsqu'une seule zone est systématiquement impactée, cela pourrait signifier un traitement de l'os particulier, avec par exemple la possibilité de chauffe pour faciliter l'extraction de la moelle.

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III. 7. Conclusions

La majorité des travaux présentés dans ce chapitre a permis d'explorer de différentes manières les données récoltées lors d'une des plus importantes expérimentations de fracturation d'os longs réalisées à ce jour, en terme de quantité d'os longs cassés.

L'étude exploratoire que nous avons menée sur le premier coup a montré tout le potentiel que l'on peut tirer du visionnage des films réalisés lors de l'expérimentation. Les premiers résultats ont mis en évidence l'influence de la morphologie des os longs dans le choix de l'emplacement du premier coup. Le type d'élément semble en effet avoir plus d'influence que les particularités individuelles. Cette première étude nous a amenés à considérer l'opposition entre comportement individuel et incidence de la morphologie osseuse dans l'étude de la répartition des coups et par là même des marques de percussion. Les résultats prometteurs de ce travail permettent d'envisager un plus large travail qui consisterait à croiser l'emplacement des coups observé sur les vidéos avec l'emplacement des marques de percussion observées sur les os. Il serait également intéressant d'établir à partir de ces vidéos des descriptions fines de la chaîne opératoire de fracturation pour chacun des individus : combien de coups avant chaque fracturation et à quel emplacement, à quel moment les individus choisissent de retirer la moelle.

Par ailleurs, lors de l'étude des restes produits par l'expérimentation, publication n°2, il nous est apparu essentiel de mettre en place une méthode efficace d'enregistrement, d'illustration et d'analyse spatiale des marques de percussion. Ce fut l'un des objectifs de la collaboration fructueuse mise en place avec T. Stavrova. Cette jeune chercheuse, spécialisée dans le SIG, a élaboré une méthode à même de répondre à nos questions. La méthode novatrice de l'analyse des « Points Chauds Optimisés » a été appliquée sur un échantillon issu de l'expérimentation intuitive. Les résultats ont permis de confirmer nos précédents résultats sur l'influence du type d'élément sur la distribution des marques de percussion en contexte intuitif.

Les méthodes d'analyses spatiales montrent aussi l'étendue des champs d'application possibles pour l'étude des marques de percussion et ce aussi en contexte archéologique. La comparaison avec les études SIG menées sur les traces laissées par les carnivores pourrait permettre notamment la discrimination de l'agent ou des agents accumulateurs au sein d'assemblages mixtes de faunes fossiles.

La publication n°3 « *A way to break bones? The weight of intuitiveness* » ne se limite pas à l'application de la méthode SIG des Points Chauds Optimisée sur un échantillon plus grand. L'étude croise une grande partie des données enregistrées durant l'expérimentation, en

particulier les données relatives aux comportements des individus avec les données issues de l'analyse des restes en laboratoire. Ainsi, il a été possible d'accéder expérimentalement à des informations essentielles concernant la fracturation osseuse, qu'il est impossible d'appréhender à partir du matériel archéologique. Nous avons pu observer des comportements très variés d'un individu à l'autre, permettant d'envisager des études complémentaires à venir pour mesurer l'impact de la position des individus dans la production de marques de percussion. Nos résultats ont mis en évidence que les modèles intuitifs sont fortement influencés par la forme des os, pour la plupart des éléments, mais pas pour tous, par exemple le fémur. La comparaison de nos résultats avec des analyses équivalentes sur des assemblages fossiles permettra de savoir si, au sein de niveaux archéologiques, les ossements ont été fracturés intuitivement ou s'il est possible de prouver la présence de traditions par opposition à nos modèles intuitifs expérimentaux. Nous avons aussi montré qu'en contexte intuitif les coups sont très nombreux et par conséquent le nombre de marques aussi, avec un important nombre de *pits* de percussion. Les modèles intuitifs identifiés peuvent varier selon le type de marques (les marques qui produisent une fracture vs. les marques qui n'en produisent pas). Ces résultats convergent aussi vers une spécificité des pratiques intuitives dans le nombre de coups donnés et le nombre de restes produits. Des études complémentaires pourraient être menées pour évaluer l'importance de la maîtrise de la technique de percussion sur l'ensemble des variables analysées dans notre travail (nombre de coups, de restes, type de marques produites mais aussi, qualité de la moelle, sa quantité, difficulté selon l'élément fracturé, position et amplitude des gestes...) et les comparer avec nos différents résultats obtenus par des volontaires non-expérimentés.

L'opportunité du stage de Master 2 conduit par L. Chevillard a permis la mise en place d'une expérimentation complémentaire. Les résultats montrent l'existence d'une variabilité de la distribution des marques de percussion lorsqu'un individu expérimenté fracture un os et ce même lorsqu'il s'arrête à la première fracture. Cependant cette variabilité est très accentuée lorsque l'expérimentateur cherche à accéder à la plus grande quantité de moelle possible et fracture l'os à plusieurs reprises. De plus, son analyse conjointe de l'emplacement des coups et des marques de percussion montre qu'en absence d'enclume la plupart des traces sont localisées aux endroits impactés. Il y a donc seulement un petit nombre de marques qui se situent dans des zones non percutées, le plus souvent proche des zones percutées. Ces enregistrements peuvent être dus au fait que les marques sont parfois grandes et sont localisées sur plusieurs zones.

Enfin, la collection expérimentale produite lors de cette expérimentation (vidéos, photos, base de données et restes osseux) sera mise à la disposition des chercheurs afin de permettre de

nouvelles études complémentaires. Son potentiel de recherche est grand, comme a pu le montrer nos différents résultats.

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Chapitre IV.
Des traditions bouchères
chez Néandertal ?

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une systématisation des gestes ?*

IV. 1. Introduction

Dans ce chapitre nous présentons les différents axes que nous avons développés en lien avec l'étude du matériel faunique des sites archéologiques. Dans le cadre de notre travail de thèse, nous avons réalisé l'étude de sept séries fauniques provenant de deux sites Moustériens français : l'Abri du Maras (MIS 3) et la grotte de Saint-Marcel (MIS 3) et d'un site italien : Riparo Tagliente (MIS 3-4). Ces analyses ont fait l'objet de deux articles : le premier publié dans la revue *Journal of Archaeological Science : Reports* (Vettese et al., 2017, **Publication n°4**) s'intéressant au seul niveau 4.1 de l'Abri du Maras et le second, dont la soumission est prévue en janvier 2020 dans la revue *Plos One* (Vettese et al., en préparation, **Publication n°5**), comparant les sept assemblages provenant de ces trois sites.

Ce chapitre a pour principal objectif d'apporter des éléments de réponse à la question de l'émergence des premières traditions bouchères dans le Sud-Ouest de l'Europe au Paléolithique moyen. A partir de l'étude de la fracturation des os longs pour la récupération de la moelle et de l'emplacement des marques de percussion, nous avons souhaité identifier la mise en place de savoir-faire et de transmissions des pratiques au sein de groupes néandertaliens. Dans cette optique, nous avons augmenté le faible corpus de sites néandertaliens déjà étudiés sous cet aspect.

Les sites étudiés (Abri du Maras, Saint-Marcel et Riparo Tagliente) sont tout à fait appropriés pour mener une telle étude (Chapitre IV. 3. 1.). Pour chaque site et chaque niveau, nous avons cherché à savoir s'il était possible de mettre en évidence l'existence de pratiques bouchères standardisées et contre-intuitives. Nous nous sommes en effet interrogés sur la possibilité ou non d'observer des traditions bouchères dans un même site, et plus largement, dans différents sites, incluant pour comparaison deux sites espagnols du Paléolithique moyen Bolomor (levels IV, IX, XIIa and XIIc) and Gran Dolina (TD10-1) (MIS 5-9), pour lesquels de telles approches avaient déjà été menées (Blasco et al., 2013). Lors de l'étude des assemblages fauniques, une question subsidiaire s'est posée sur l'impact des altérations taphonomiques sur l'identification et la caractérisation des marques de percussion en fonction des différents contextes dépositionnels.

Enfin, dans une approche intégrative, nous avons comparé nos résultats avec les données archéologiques propres à chacun des sites afin d'établir de possibles liens entre les cultures lithiques, les stratégies de chasse ou encore les stratégies de traitement des carcasses.

Ces travaux se basent également sur notre révision de la nomenclature et de la terminologie des marques de percussion. En effet, comme nous avons pu le constater, la

multiplicité des termes employés et la difficulté de différencier les marques de percussion *sensu stricto* des marques consécutives à la fracturation pouvaient être un frein à leur identification, leur caractérisation et de ce fait à leur exacte localisation sur les os longs (Chapitre II). Par ailleurs, grâce aux données de notre expérimentation (Chapitre III), nous avons pu comparer les schémas intuitifs de distribution avec ceux des séries archéologiques, et ainsi démontrer dans certains cas la présence de comportements contre-intuitifs, et donc possiblement traditionnels.

Pour commencer, nous présenterons l'étude réalisée sur le niveau 4.1 de l'Abri du Maras (Chapitre IV. 2., **Publication n°4**). Cette étude fait suite à notre travail de Master. Après les travaux de Blasco et al. (2013), ce fut la seconde analyse publiée s'intéressant à la question des traditions bouchères dans un site Néandertalien par le prisme de l'étude de la distribution des marques de percussion. Une autre étude s'est focalisée, quant à elle, sur cette question de traditions bouchères sur la période du Paléolithique supérieur, mettant en lumière des pratiques de percussion standardisées (Masset et al. 2016). Nos résultats n'avaient pas pu mettre en évidence de traditions bouchères spécifiques aux groupes ayant occupé l'Abri du Maras lors du remplissage sédimentaire du niveau 4.1.

Dans la continuité de ce premier travail, dans le cadre d'un article qui sera prochainement soumis à la revue Plos One (janvier 2020), nous avons étendu notre aire géographique d'étude en analysant plusieurs autres séries provenant de trois sites occupés par des Néandertaliens : l'Abri du Maras et la grotte de Saint-Marcel qui sont des sites du Sud-Est de la France (Ardèche) et Riparo Tagliente, qui est situé dans le Nord-Est de l'Italie (Chapitre IV. 3., **Publication n°5**). Ce travail a permis de mener une analyse comparative à l'échelle du Sud-Ouest de l'Europe pour plusieurs niveaux archéologiques sub-contemporains, incluant les sites espagnols (Bolomor et Grand-Dolina).

IV. 2. La fracturation des os longs par Neandertal : Schémas standardisés ou aléatoires ? L'exemple de l'Abri du Maras (Sud-Est de la France, MIS 3)

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Neandertal long bone breakage process:

Standardized or random patterns?

The example of Abri du Maras (Southeastern France, MIS 3)

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The identification of social learning processes and knowledge transmission mechanisms in the archaeological record is a matter currently explored on lithic record but not very often on faunal assemblages. As soon as the Middle Palaeolithic, the uniformity and orientation of cut marks or patterns of bone breakage may represent very useful tools to highlight butchery traditions. Following this line of research, we have tried to identify standardized actions on bones in the process of marrow recovering and therefore butchery cultural learning within Neandertal groups at Abri du Maras (MIS 3, Southeastern France). The detection of culturally-induced patterns involves the discrimination of those generated intuitively, which depend on conditioning factors such as bone density or skeletal morphology. To tackle this issue, we have used a zooarchaeological approach focused on the morphology and location of damage caused during the bone breakage process (percussion marks and scraping marks). We also compare our data with previously published results both at a zooarchaeological and experimental level. Our work indicates that the bone remains from layer 4.1 at Abri du Maras do not reveal standardized patterns of long bone breakage in terms of distribution of impact notches along long bone shafts and then imply two hypotheses: 1) the presence of several groups with various butchery practices during the sedimentary formation and the marked palimpsest character of this layer or 2) the presence of individuals within one single group which do not share similar butchery know-how.

Keywords: Middle Palaeolithic, Neandertal, Long bone, Breakage patterns, Butchery, Cultural practices

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IV. 2. 1. Résumé long en français

Encore récemment, la connaissance de traditions culturelles chez Néandertal reposait principalement sur la base d'études portant sur la nature des outils lithiques et leurs techniques de taille. Ainsi, l'analyse du matériel lithique permettait de formuler des hypothèses sur l'identification des processus d'apprentissage social et des mécanismes de transmission intergénérationnelle au sein de groupes en contexte archéologique. En revanche, l'appréhension des sociétés et des pratiques culturelles à partir des techniques bouchères est une approche beaucoup moins développée, d'autant plus pour les périodes anciennes du Paléolithique.

Pourtant, dès le Paléolithique moyen, l'étude des restes osseux montre la présence à la fois de traces de découpes standardisées et préférentiellement orientées et de modèles de fracturation osseuse normalisés (Blasco et al., 2013 ; Castel et al., 2017 ; Soulier and Costamagno 2017 ; Stiner et al., 2011). La présence d'une uniformisation des traces anthropiques et notamment de boucherie au sein de niveaux archéologiques a démontré que les restes osseux pouvaient donc tout aussi bien servir d'outils méthodologiques pour mettre en évidence des traditions ou des savoir-faire techniques.

L'étude comparative des marques de percussion des sites espagnols de Gran Dolina (MIS 9) et de Bolomor (MIS 5) a mis en évidence la présence de traditions bouchères. Ces traditions ont été identifiées au sein du groupe ayant occupé le niveau IV de Bolomor (Blasco et al. 2013). La spécificité des pratiques bouchères observée dans ce niveau a pu être mise en évidence grâce à l'analyse de la distribution des marques de percussion effectuées lors de la récupération de la moelle jaune des os longs. Au contraire, les résultats obtenus dans le site de Gran Dolina (TD10-1) allaient plutôt dans le sens de plusieurs groupes humains de cultures variées ayant occupé brièvement et successivement ce site, produisant des palimpsestes d'occupations.

L'analyse des marques de percussion est donc un outil méthodologique qui peut s'avérer efficace pour identifier des traditions bouchères. Ces marques résultent d'une action directe sur l'os. Contrairement aux marques de découpe, elles sont aussi moins directement inféodées à la morphologie de l'animal. En effet, les incisions pour découper les peaux ou les chairs ne marquent les os qu'accidentellement et non à dessein, à des endroits particuliers du squelette, dépendants des insertions musculaires, tendineuses ou ligamenteuses. Ces traces sont des épiphénomènes (Soulier et Costamagno 2017 ; Lyman 1994), à l'exception peut-être des marques de raclage qui, comme les traces de percussion, peuvent contribuer à la mise en évidence de traditions bouchères du fait qu'elles proviennent aussi d'une action directe et intentionnelles sur l'os.

Afin d'étendre le corpus de sites étudiés sous cet angle, nous nous sommes intéressés à un niveau anthropisé du site de l'Abri du Maras : le niveau 4.1 (MIS 3, Sud-Est de la France). Ce niveau nous est apparu approprié pour une étude de la morphologie et de la localisation des marques produites lors de la fracturation des os longs (marques de percussion et de raclage) au vu de la quasi absence de traces de carnivores et de l'assez bonne conservation du registre osseux. De plus, nous avons pu identifier des traces laissées par chacune des étapes de la chaîne opératoire bouchère sur les carcasses, et en particulier des marques de percussion. Les os longs ont été fracturés systématiquement, et ce, indifféremment de l'espèce ou de l'élément osseux. Par conséquent, nous avons cherché à identifier des actions standardisées à partir de la localisation des traces de percussion sur les fragments de diaphyse des os longs produites lors de l'extraction de la moelle jaune.

Au sein de la couche 4.1 de l'Abri du Maras, la distribution des marques de percussion sur les diaphyses osseuses ne nous a pas permis de démontrer l'existence d'un modèle systématique de fracturation des os longs. Cette assertion implique deux hypothèses concernant les traditions bouchères des groupes ayant occupé l'abri lors du remplissage de ce niveau : 1- la présence de plusieurs groupes avec des pratiques différentes (palimpsestes) ou 2- la présence de plusieurs individus au sein d'un même groupe qui ne partageaient pas un même savoir-faire boucher.

La question de l'identification de traditions bouchères au Paléolithique moyen au sein de groupes Néandertaliens est centrale pour une meilleure compréhension des mécanismes de transmission intergénérationnelle des pratiques et des techniques. Cette présente recherche apporte de nouvelles données sur la relation entre la consommation de matières animales et les contextes socio-culturels des groupes humains de cette période, et cela au regard de l'apprentissage des techniques bouchères, de la systématisation des gestes et de la dextérité dans le traitement des carcasses. Des études complémentaires permettant de relier les traditions bouchères et les cultures techniques lithiques dans le monde néandertalien ont permis d'appréhender dans leur globalité les notions d'apprentissage et transmission des savoir-faire au sein des sites du Paléolithique moyen.

Pour toutes ces raisons, il nous a semblé nécessaire d'augmenter le corpus de sites et de niveaux archéologiques étudiés selon cette optique (Chapitre IV. 3.). Par ailleurs, l'augmentation du corpus expérimental s'intéressant à la manière intuitive d'extraire la moelle des os longs ont pu permettre d'évaluer l'impact de la taille des animaux et de la morphologie spécifique de chaque élément sur la distribution des marques (Chapitre III).

Les résultats d'une telle étude permettent de se questionner sur la présence de mécanismes d'apprentissage et de la mise en place de pratiques systématisées de boucherie au sein de groupes Néandertaliens. La présence de schémas répétitifs et contre-intuitifs d'extraction de la moelle osseuse permettrait de caractériser la présence d'une pratique bouchère spécifique.

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IV. 2. 2. *Publication n°4*

Neandertal long bone breakage process: standardized or random patterns? The example of Abri du Maras (Southeastern France, MIS 3).

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The identification of social learning processes and knowledge transmission mechanisms in the archaeological record is a matter currently explored on lithic record but not very often on faunal assemblages. As soon as the Middle Palaeolithic, the uniformity and orientation of cut marks or patterns of bone breakage may represent very useful tools to highlight butchery traditions. Following this line of research, we have tried to identify standardized actions on bones in the process of marrow recovering and therefore butchery cultural learning within Neandertal groups at Abri du Maras (MIS 3, Southeastern France). The detection of culturally-induced patterns involves the discrimination of those generated intuitively, which depend on conditioning factors such as bone density or skeletal morphology. To tackle this issue, we have used a zooarchaeological approach focused on the morphology and location of damage caused during the bone breakage process (percussion marks and scraping marks). We also compare our data with previously published results both at a zooarchaeological and experimental level. Our work indicates that the bone remains from layer 4.1 at Abri du Maras do not reveal standardized patterns of long bone breakage in terms of distribution of impact notches along long bone shafts and then imply two hypotheses: 1) the presence of several groups with various butchery practices during the sedimentary formation and the marked palimpsest character of this layer or 2) the presence of individuals within one single group which do not share similar butchery know-how.

Keywords: Middle Palaeolithic, Neandertal, Long bone, Breakage patterns, Butchery, Cultural practices

1. Introduction

From 400 ky onwards, many sites in Europe and the Near East attest to the improvement of hunting strategies and carcass processing. The discovery of spears at the sites of Schöningen (Germany) and Clacton-on-Sea (England) shows the range of innovations already in use as early as the Lower Palaeolithic (Thieme, 1997; Oakley et al., 1977; Schoch et al., 2015). Within human groups, meat consumption remains indicate the generalization of new collective practices: selective transport and processing of selected skeletal portions at the camp; systematization of butchering practices (task specialization) and meat sharing (e.g., Pamies et al., 2001; de Lumley et

al., 2004; Moigne et al., 2005; Stiner et al., 2009, 2011; Sam and Moigne, 2009; Daujeard et al., 2010; Blasco et al., 2014b).

Analyses of the lithic material result in the identification of technical traditions and are assumed to be the characteristic markers of a group and of an inter-generational transmission of knowledge from the Early Palaeolithic phases onwards (e.g., Moncel et al., 2012, 2014 ; Stapert, 2007; Turq et al., 2013; Faivre et al., 2014). On the other hand, the assessment of specific group traditions based on butchering techniques is a much lesser developed approach. Studies of butchery marks generally consist in identifying butchery activities or in differentiating them from marks left by other taphonomic agents (carnivores, trampling, etc.) (Blumenschine and Selvagio 1991, Pickering and Egeland 2006, Domingo-Rodriguez 2009, Galán et al. 2009). Our knowledge of the social organization of human groups based on the fossil bone record is mainly focused on the hunting techniques. For example, mass kill sites of large ungulates are associated with organized hunts, requiring the presence of a group of several individuals (Gaudzinski, 1995; Rendu, 2010; Delagnes and Rendu, 2011).

Butchering techniques, in the same way as core technologies or tool retouches, provide an innovative avenue of research for attempting to define the specific traditions of a human group through a possible standardization of their butchering practices. This is the hypothesis advanced by Blasco et al. (2013), based on a comparison of the notch distribution patterns at two Spanish Middle Pleistocene sites: Bolomor Cave –levels XVII (sublevels XVIIa and XVIIc), XI and IV (MIS 9-5e) and Gran Dolina, Atapuerca –sublevel TD10-1 (upper part, *ca.* MIS 9). Bolomor IV showed a strong bone breakage pattern, which is far from the intuitive standardization depending on factors such as the bone density and/or skeletal morphology, as observed experimentally. These patterns therefore were interpreted as culturally-induced. On the contrary, the rest of levels of Bolomor (e.g., XVIIa) and TD10-1 (upper part) of Gran Dolina show no preferential areas to break open the limb bones; circumstance that was interpreted as the result of the presence of several groups with different ways of processing the carcasses (palimpsest composed of several human occupations). On this basis, we try here to assess the existence of cultural traditions on another long bone assemblage accumulated by Neandertals in Abri du Maras (layer 4-1, MIS 3, France). This site presents an advantage in that quasi-absence of carnivore intervention is recorded on the bones. In order to carry out this study, we analysed the bone assemblage by using a zooarchaeological approach focused on percussion marks. We then compared our results with the experimental and the archaeological data of Blasco et al. (2013).

2. Chronological, environmental and archaeological frameworks

Abri du Maras (South-East France, Saint-Martin d'Ardèche) is a vast rock-shelter located at the exit of the Ardèche gorges, in a dry valley. It is about 1 km from the present day river bed, on its left bank, and 7 km from the Rhône Valley River mouth (Figure 1). The site is at an altitude of 170 m. Today, the southeast facing shelter is 12 m long, 3 m wide, with an internal height of 2 m (Combier, 1967).

Abri du Maras was excavated in the 1950s-1960s by R. Gilles and J. Combier. These first excavations unearthed a stratigraphic sequence made up of eight archaeological levels (Combier, 1967). In 2006, a test pit was opened to assess the available data from the site and led to the reopening of excavations in 2006 (Moncel et al., 2010). Since then, the site is excavated each year as part of a programmed project directed by M.-H. Moncel.

These recent excavations have mainly focused on level 4, which corresponds to a heterogeneous silty deposit attributed to the beginning of the last glaciation (MIS 3) (Moncel and Michel, 2000; Richard et al., 2015). The coarse fraction of the sedimentary deposits is due to the dismantling of the wall as a result of cryoclastic disturbances. It is divided into two main occupation layers (4-1 and 4-2), separated by an almost sterile loessic level. Layer 4-1, the subject of the present study, was excavated over more than 40 m². The thickness of layer 4-1 is on average of 30 cm and the concentration for the archaeological remains is of 439 remains/m³ and specifically for the faunal remains of 228/m³. Thirteen ashy lenses have been discovered *in situ* at various depths and the use-wear data point to a wide variety of on-site domestic activities, including activities other than butchery (Hardy et al., 2013).

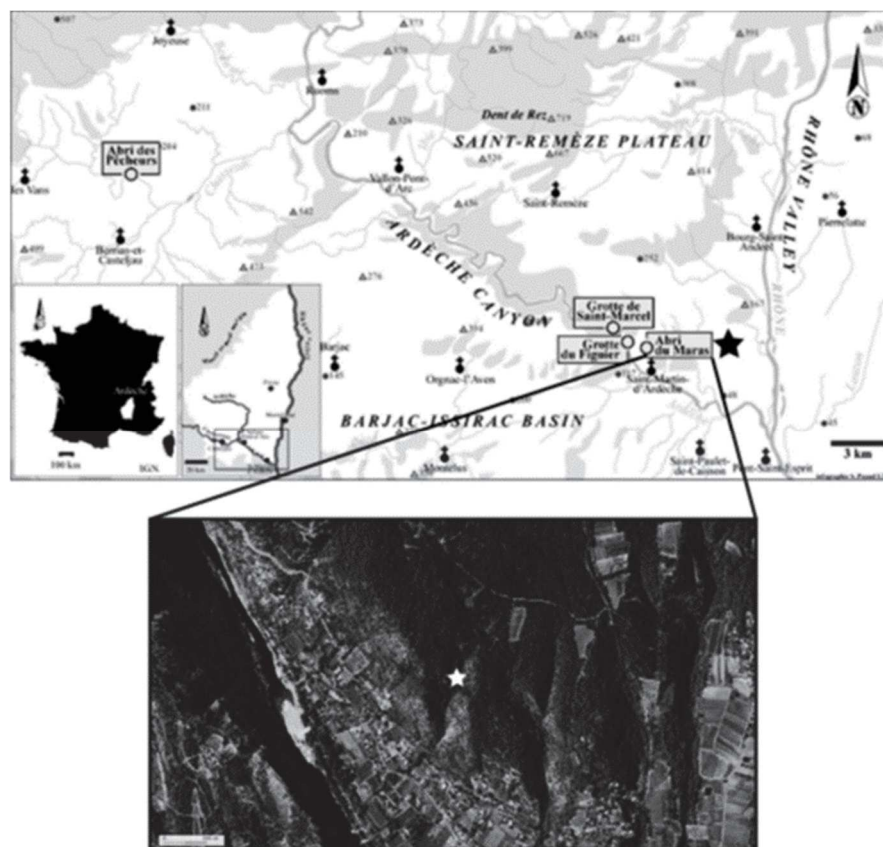


Figure 1: Location of Maras rock shelter south-eastern France. View of the topographical position of the site in a small valley near the Ardèche River (in Moncel et al. 2014).

The occupation phase of layer 4-1 indicates specialized autumnal reindeer hunts and an intense on-site butchering activity. The large fauna points to a cold and dry climate and an open steppic landscape favourable to large gregarious ungulates, with, in decreasing order of importance; the reindeer (*Rangifer tarandus*), the horse (*Equus ferus* cf. *germanicus*), the megaloceros (*Megaloceros giganteus*), the red deer (*Cervus elaphus*), the bison (*Bison priscus*) and the ibex (*Capra ibex*). Several Lagomorph remains have also been identified. No carnivore remains have been recorded. The taphonomy of the fauna revealed almost exclusively anthropogenic accumulation processes. There are few carnivore marks (less than 1% of the total legible remains) and cut marks are very frequent (more than 25%). Ungulates are represented by all age classes. The skeletal profiles for the reindeer and the horse indicate the existence of initial processing at the kill sites and a transport strategy of skeletal parts (Daujeard and Moncel 2010).

The lithic industry from layer 4-1 is a Middle Palaeolithic industry with predominantly Levallois core technology (Combier, 1967; Moncel et al., 1994; Moncel, 2005). The first studies conducted by J. Combier (1967) and R. Gilles in the upper layers of the sequence revealed the presence of a Mousterian with blade-type Levallois debitage. This preferential use of Levallois

debitage was once again observed during recent excavations in the lower part of the infilling. The abundance of the series in layer 4-1 allows for the description of both complete and partial operative sequences (debitage on imported large flakes). The largest blades, points and flakes were knapped before being brought to the site, where they were then used on-site. They point to an anticipation of tool kit requirements (Moncel et al., 2014). The raw materials of these pieces come from sectors located less than 20 km to the north and south of the site, on the right bank of the Rhône (Moncel et al., 2014). The activities carried out on-site required additional tools to these scant large artefacts. The importation of previously knapped products, as the presence of partial reduction sequences, suggests that the rock shelter was occupied for short-term periods (Moncel et al., 2014).

3. Material and Methods

3.1 Sample

The studied material comes from layer 4-1 of Abri du Maras, excavated from 2006 to 2013. Our analysis only concerned the long bone remains from middle and large-sized ungulates. In layer 4-1 the proportion of long bone fragments among the total Number of anatomically Identified Specimens (NISPa) is very important (60.16%; N = 808/1343). Thus, 808 long bone remains were studied, 730 of which were taxonomically identified. Despite their abundance in the sample, we did not include the indeterminate bone splinters in our analysis. This choice is justified by the necessity to avail of detailed data concerning the localization of impact marks within anatomical elements.

3.2 Taphonomy

We used the following count indexes (Binford, 1981; Lyman 1994, Brugal et al. 1994): the total Number of Remains (NR); the Number of taxonomically Identified Specimen (NISPt); the Number of anatomically Identified Specimen (NISPa); the Minimum Number of Elements (MNE); the Minimum Number of Individuals (MNI) and the Minimum Animal Unit (MAU). We recorded anatomical, taxonomic and surface modification data for all recorded and identified specimens.

The three dimensions (length, width, thickness) were measured for each element. The shaft fragments were differentiated by size and circumference classes (cf. Villa and Mahieu, 1991 $0 < L1 < 0.25 \leq L2 < 0.5 \leq L3 < 0.75 \leq L4 \leq 1$; $0 < C1 < 0.5 \leq C2 < 1$; $C3 = 1$). In order to take into account the

taxonomically indeterminate fragments, we established two main size categories adapted to the studied ungulates:

- Medium-sized ungulates (MUNG) with a weight between 100 and 300 kg (reindeer and red deer);
- Large-sized ungulates (LUNG) with a weight between 300 and 1,000 kg (horse, bison and megaceros).

The long bones were studied using a classical taphonomic and zooarchaeological approach. All the bone surfaces were observed with naked eyes under a low-angled light and a stereomicroscope (Leica S8 APO x10-80) when necessary. For each faunal remain, we systematically recorded the different taphonomic alterations (meteorological, geological and biological) using the criteria established by Behrensmeyer (1978), Binford (1981), Lyman (1994) and Blumenschine et al. (1996) (among others). The illegible remains were not included in the percentages.

Burnt damages were recorded according to the different colour stages used by Stiner et al. (1995) but simplified into three main stages:

- stage 1: lightly burnt (colour: mainly brown);
- stage 2: carbonized (colour: mainly black);
- stage 3: calcined (colour: mainly white).

The works of Binford (1981), Shipman and Rose (1984), Behrensmeyer et al. (1986), Olsen and Shipman (1988) and Dominguez-Rodrigo *et al.* (2009 a), enabled us to distinguish butchery striations from trampling ones. Adapted from the definition of Lyman (2008), we recorded two types of striations: incisions and scraping marks. Chopping marks were recorded as a type of percussion marks. Using the localization and morphology of these marks on the skeleton, it was possible to interpret the butchery activity (Binford, 1981; Valensi, 1991; Nilssen, 2000; Pobiner et al., 2008). Apart from scraping marks, following on Blasco et al. (2013), butchering striations were not taken into account in this study of standardization butchering gestures. Indeed, the cut marks location is linked to the morphology and size of the animal. Besides that, the frequency of cut marks may also be related to the dexterity of the butcher. And finally, their variability, both in their occurrence and morphology, depends to the raw material, the type of tool and the type of action developed (e.g. Dominguez-Rodrigo *et al.* 2009 b; Val *et al.* 2017).

3.3 Fracturation

Post-depositional and fresh bone fractures were identified based on the fracture features (Villa and Mahieu, 1991). Specific analyses were carried out concerning long bone marrow processing (percussion marks and scraping marks). Yellow marrow from long bones can be extracted using two main methods: the bone can be struck on an anvil with a hammer with or without retouch (whereby the bone has a passive role), or the bone can be fractured directly against an anvil or a wall by “batting” (where the bone has an active role) (Blasco et al., 2014a; Rovira and Caceres, 2013). In order to identify the preferentially impacted zones, we localized each fragment according to its long bone portion (**Figure 2**). The recorded percussion marks are (Blumenshine and Selvaggio, 1988; 1991; Capaldo and Blumenshine, 1994; White, 1992 ; Blasco et al., 2013):

- medullary or cortical percussion notches (negative flake scars);
- impact flakes (positive flake scars);
- percussion pits;
- adhering flakes;
- peeling;
- micro-notches (very small notch present in the centre of the percussion notch)

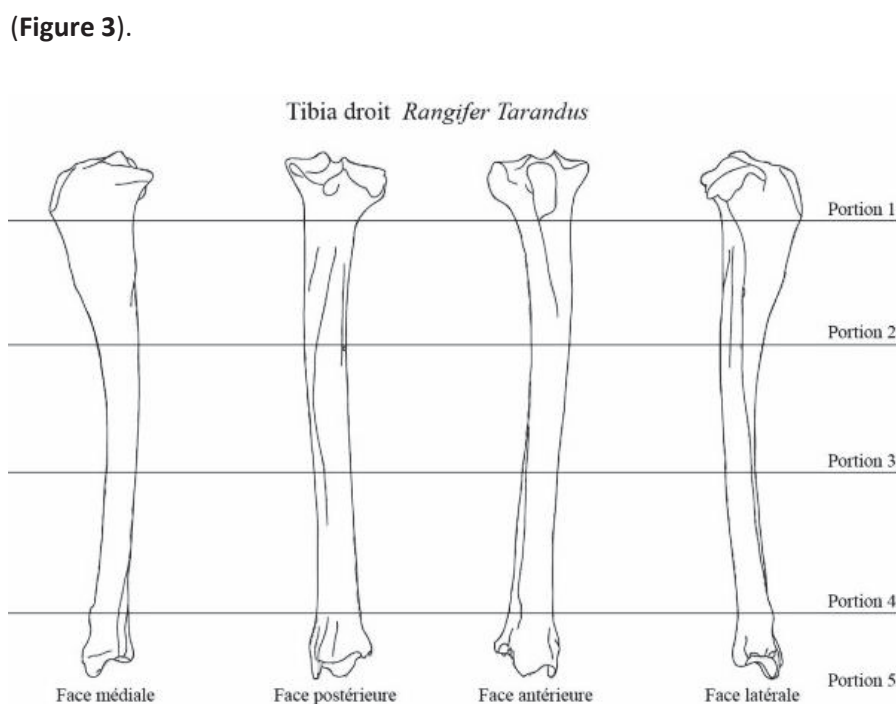


Figure 2: Example of the nomenclature used in the description of the bone portions and surfaces. Portion 1 (P1): proximal articular end; Portion 2: proximal diaphysis; Portion 3: medial diaphysis; Portion 4: distal diaphysis; Portion 5: distal articular end (after the drawing by Castel (2010), reference J. C. Castel (Geneva Museum) - © 2013 archéozoo.org).

The depth of the notches was taken into consideration using three different categories: d1 ($< \frac{1}{2}$ initial cortical height), d2 ($> \frac{1}{2}$ and < 1 initial cortical height) and d3 ($= 1$, totality of the cortical height). Percussion on an anvil with a non-retouched pebble sometimes produces counterblows (Rovira and Caceres 2013). We also registered opposite notches resulting from counterblows (double opposing notches) (Galan et al., 2009). These double notches are observed on the remains as two notches located in the same portion but on exact opposite sides.

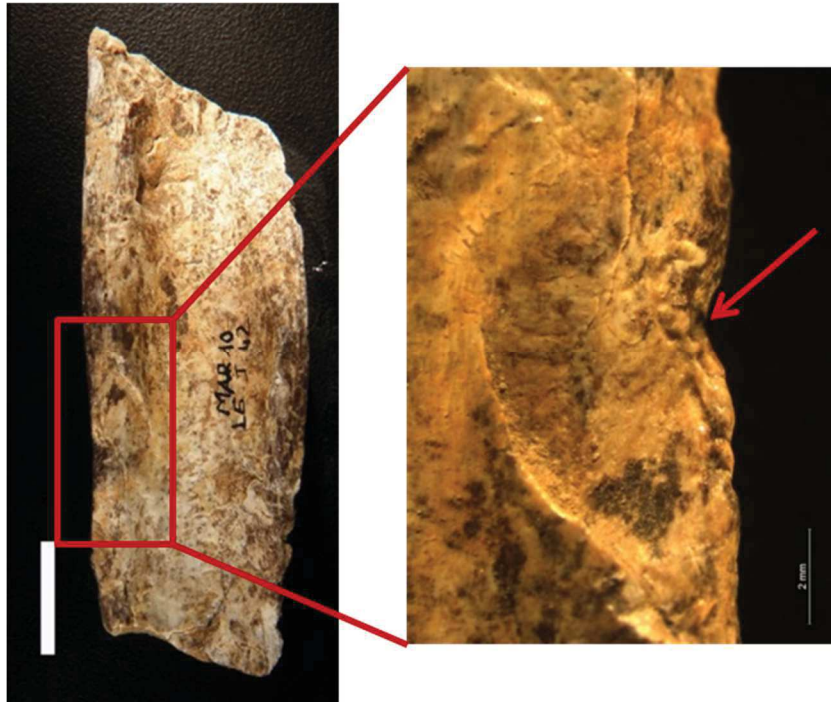


Figure 3: Percussion marks of a reindeer metacarpal (scale 1cm and 2mm). We can observe a micro-notch on the magnified picture (red arrow).

3.4 Experimental data

To distinguish intuitive from counter-intuitive way to break long bones among archaeological data, we use comparative experimental data from of Blasco *et al.* (2013). Indeed, one of the objectives of the experimentations of Blasco and colleagues was to decipher intuitive behaviours during marrow processing made by non-trained experimenters. These latter used two different methods to hit long bones of adult cows (humeri, radio-ulnas, femurs and tibias): by batting (six experimenters) and by hammerstone on anvil (eight individuals). We compare the data obtained for each method with the ones from our archaeological data and those from Bolomor and Gran Dolina (Blasco et al., 2013, supplementary data).

3.5 Data analysis

Spearman's test was used to evaluate the correlation between the %MAU and long bone density indexes and thus the existence of a differential preservation within the archaeological faunal assemblage. We also employed this bivariate test to cross the %MAU and the medullary cavity volume of reindeer long bones (Jones and Metcalfe, 1988) to explore the human carcass transport strategies. To evaluate the influence of bone features (density and morphology) on the location of percussion impacts, we statistically crossed the frequencies of percussion marks by portion with long bone density indexes (Lyman, 1994; Lam et al., 1999). Those correlations were only tested for medium-sized ungulates and shaft portions. For the few large sized-ungulate remains, we used descriptive statistic because of the scarcity of remains. These coefficients were calculated and their statistical significance tested using the software PAST (Hammer et al., 2001). We used an alpha of 0.05 for all the tests performed.

As Cochran's rules was not respected, we used Fisher exact tests with R (R core team, 2016) to test the independence between the frequency and location of impacts on both middle- and large-sized ungulates shafts individually and also for both of them, additionally. Correspondence analysis (CA) was used in order to investigate the potential existence of counter-intuitive butchery patterns. For the CA, we choose to take into account only medium-sized ungulates for Abri du Maras because of its reindeer-dominant faunal spectrum. The sample of layer 4-1 of Abri du Maras was compared with archaeological samples of Bolomor (IV, XVIIa, XVIIc) and Gran Dolina (TD-10-1 [upper part]) and with two experimental series (long bone breakage process by batting and with hammerstone on an anvil: data from Blasco et al., 2013). We discarded Bolomor level XI because of low quantity of material recovered during the excavation of this sedimentary unit. Following Blasco and colleagues, we studied only humeri, radio-ulnas, femurs and tibias. Metapodials were discarded because of their absence in the experimental samples. CA were computed with the library Factomin'R (Le et al.2008).

4. Results

4.1 Zooarchaeological and taphonomic features of the long bone sample

Among the studied sample, reindeer largely dominate the spectrum, reaching more than 90% of the NISP. Horse, megaceros, red deer and bison are following. Most of the individuals are adults, and only three reindeer remains belong to juveniles (**Table 1**). Among indeterminate remains, the medium-sized ungulates are largely dominant.

The best-represented long bones for medium-sized ungulates are the metatarsals (100% of the MAU), followed in order of abundance by the humeri, radio-ulnas, tibiae, metacarpals and femurs (Table 2). Concerning possible strategies in the selection of the long bones, we correlate the %MAU of medium-sized ungulates with the volume of the medullary cavity. The %MAU and the volume of the medullary cavity are not significantly correlated ($\rho = 0.257$; $df = 5$; $t = 0.848$, $p > 0.05$).

Species	NISPt	%NISP	MNI	%MNI	MNIjuv
<i>Rangifer tarandus</i>	680	93.2%	19	68%	3
<i>Equus caballus</i> cf. <i>germanicus</i>	21	2.9%	2	7%	0
<i>Megaloceros giganteus</i>	15	2.1%	2	7%	0
<i>Bison</i> sp.	6	0.8%	1	4%	0
<i>Cervus elaphus</i>	4	0.5%	1	4%	0
<i>Rangifer/Capra</i>	2	0.3%	1	4%	0
<i>Cervus/Rangifer</i>	1	0.1%	1	4%	0
<i>Megaloceros/Cervus</i>	1	0.1%	1	4%	0
Total	730	100%	28	100%	3
MUNG IND	59	76%			
LUNG IND	19	24%			
TotalL IND	78	100%			
Total	808				

Table 1 : Number of remains for the archaeological studied sample (NISPt and MNI).

	NISPa	%NISPa	L	R	ind	juv	MNE	MAU	% MAU	Max (mm)	Min (mm)	Mean (mm)
MUNG (Total)	742	100%	165	190	387	11	225	112.5		193	16	57.4
Humerus	97	13%	32	40	25	0	34	17	55%	123	23	54.9
Radius	123	17%	34	32	57	1	41	20.5	66%	193	22	59.6
Metacarpal	58	8%	13	14	31	2	19	9.5	31%	181	16	60.3
Femur	45	6%	8	12	25	0	17	8.5	27%	110	28	61.4
Tibia	184	25%	53	58	73	3	41	20.5	66%	166	16	63.5
Metatarsal	167	23%	24	33	110	2	62	31	100%	150	16	56.9
Metapodial	68	9%	1	1	66	3	11	5.5	18%	101	16.6	45.2
LUNG (Total)	66	100%	33	13	20	0	16	8		226	35	103.3
Humerus	5	8%	1	2	2	0	2	1	40%	78	55	70.6
Radius	8	12%	4	1	3	0	2	1	40%	156	73	108.3
Metacarpal	2	3%	1	0	1	0	0	0	0%	226	62	144
Femur	9	14%	3	4	2	0	2	1	40%	142	38	102.8
Tibia	28	42%	11	6	11	0	5	2.5	100%	161	49	84
Metatarsal	14	21%	13	0	1	0	5	2.5	100%	219	35	110.4
Metapodial	0	0%	0	0	0	0	0	0				
Total	808											

Table 2: Number of anatomically Identified Specimen (NISPa), Left (L) and Right (R) sides, Number of Indeterminate Remains (ind), Number of Remains belonging to juveniles (juv), Minimum Number of Element (MNE), Minimum Animal Unit (MAU), maximal length (Max), minimal length (Min) and mean size of long bones (Mean).

Long bones are highly fragmented. We count only four complete bones: two left metacarpals and one right metatarsal of reindeer and a right metacarpal III of horse. Shaft bone portions are far more numerous than articular portions (**Table 3**). The % MAU and the bone density indexes of medium-sized ungulates are positively and significantly correlated ($\rho = 0.865$; $df = 29$; $t = 3.593$, $p < 0.05$) (**S1**). Thus, the low rate of epiphysis portions compared to diaphysis could be explained by the differential preservation. They may also have been used as fuel or crushed to extract bone grease of spongy parts (Daujeard, 2008; Moncel and Daujeard, 2010).

About one quarter of the remains have illegible surfaces (**Table 4**). Root etchings have caused the dissolution of most of the bone surfaces. Percussion notch analyses were not directly impacted, but that is not the case for peeling and percussion pits on bone surfaces that may have been unnoticed. Only two remains show carnivore marks (pits) and there are no digested elements, nor carnivore remains.

	Epiphysis	Diaphysis	E/D
MUNG	162	888	0.18
LUNG	21	90	0.23
Total	183	978	0.19

Table 3: Number of epiphysis and diaphysis long bone portions and ratios of epiphysis on diaphysis (E/D).

	Root etchings								Illegibility		Total
	v0		v1		v2		v3		NR	τ	NR
MUNG	29	3.9%	246	33.2%	270	36.4%	197	26.5%	180	24.3%	742
LUNG	4	6.1%	16	24.2%	20	30.3%	26	39.4%	25	37.9%	66
Total	33	4.1%	262	32.4%	290	35.9%	223	27.6%	205	25.4%	808

Table 4: Main bone surface alterations (NR and τ).

Supplementary information 1

Fragmentation occurred mostly at the time of the human occupations. Indeed, more than 90% of the remains bear one or several green bone fractures, according to the criteria established by Villa and Mahieu (1991) (**Table 5**). Fractures profiles are mainly curved/V-shaped along with oblique angles and smooth edges. All types of long bones were broken for both middle and large-sized ungulates. The vast majority (more than 80%) have been reduced to a C1 circumference and have a L1/L2 length (**Figures 4 and 5**). Post-depositional breakage damaged one third of the total remains. Secondary frost action and sediment compaction had only a low effect on bone fragmentation.

Among our sample, we observe only ten burnt bones, nine for medium-sized ungulates and one for large-sized. This last one is calcined, like two of the medium-sized ungulate remains. Among these latter, three other are carbonized and four have just been lightly burnt (brown colours) (**Table 6**).

	Gelifraction		Green		Dry		Ind		Total
MUNG	16	2.2%	682	91.9%	221	29.8%	91	12.3%	742
LUNG	2	3.0%	59	89.4%	21	31.8%	3	0.4%	66
Total	18	2.2%	741	91.7%	242	30.0%	94	11.6%	808

Table 5: Frost, green, dry and indeterminate long bone breakage (NR and τ).

	stage 1	stage 2	stage 3	NRT
MUNG	4	3	2	9
LUNG	0	0	1	1
Total	4	3	3	10

Table 6 : Number of remains with burnt damages (stages 1 to 3).

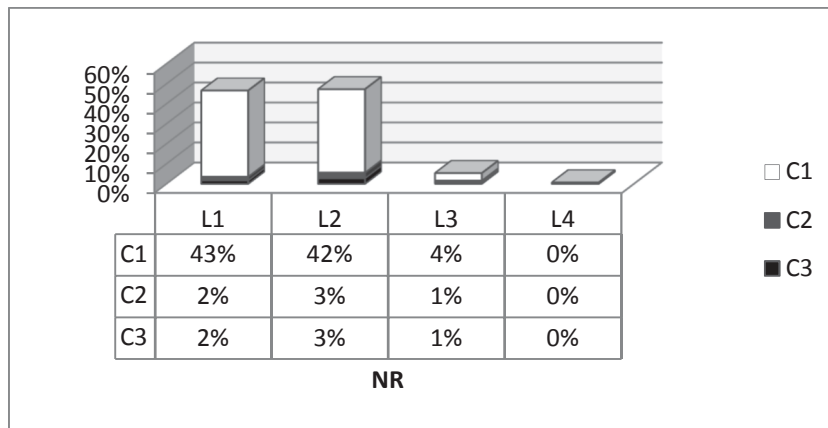


Figure 4 : Diagram showing relative frequencies of shaft length and circumference for MUNG (medium-sized ungulates) long bone elements.

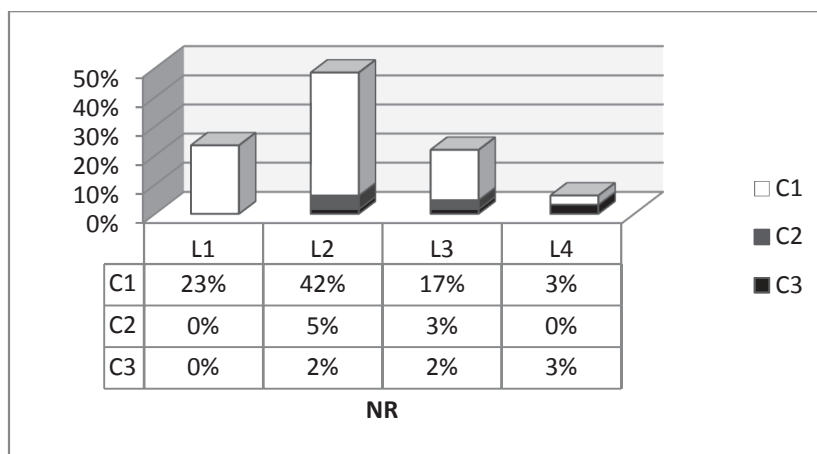


Figure 5 : Diagram showing relative frequencies of shaft length and circumference for LUNG (large-sized ungulates) bone elements.

Cut marks are documented on 224 bones (37%; **S2**). Incisions and scraping marks have been identified. Cut marks analysis enabled us to identify disarticulating, defleshing, tendon removals and skinning activities. Scraping marks represent 15% of the cut marks and they are present on 6% of the long bone elements for the medium-sized ungulates and 13% of those of large-sized (illegible remains discarded). For this class of ungulate, only tibia and metatarsal bear scraping marks. For the medium-sized ungulates, all the long bones have scraping marks. For radio-ulnas and metacarpals, nearly 30% of the cut-marks are scraping marks. For humeri this rate decreases to less than 20% and we have 12% for tibias and metatarsals. Scraping marks on femurs are few and represent only 6% of the total cut-marks.

Nearly 90% of the scraping marks present on the metatarsals are present all along the anterior and posterior grooves. For the metacarpals, they are all located on the anterior surface of the bone. For the other long bones, they are unequally distributed over the shaft.

Supplementary information 2

4.2 Long bone breakage process

We identified 220 long bone elements with diagnostic marks of intentional anthropogenic breakage, which represents one quarter of them. These marks are mainly percussion notches or impact flakes (**S3**). Positive flake scars were discarded because of the numerous bone splinters difficult to localize. Incipient percussion pits are rare (1) and peelings were not noticed, partly due to the poor conservation of the bones surfaces (root etchings). We did not identify adhering flakes in our archaeological sample. Apart from the metapodials, more than half of the scraping marks are associated with impact marks and are thus the result of bone surface preparation for

fracturing (**S3**). For the metapodials, scraping marks may be the result of another unidentified butchering activity (tendons removal or skinning), not necessarily linked to breakage.

Supplementary information 3

Concerning the taxa distribution, megaceros (33%) have by far the highest proportion of percussion notches, followed by horse (29%), red deer and reindeer (25%) (**Table 7**). Bison (17%) has the lowest number of percussion marks. Notches are more abundant on tibias and humeri (37%) and on femurs (35%) and then metacarpals (22%), metatarsals (20%) and radio-ulnas (18%) (**Table 8**).

	NR	PM	
		NR	%
<i>Rangifer tarandus</i>	680	168	24.7%
<i>Equus caballus</i>	21	6	28.6%
<i>Megaloceros giganteus</i>	15	5	33.3%
<i>Bison sp.</i>	6	1	16.7%
<i>Cervus elaphus</i>	4	1	25.0%
IND	87	28	32.2%
HUM	102	37	33.3%
RAU	131	26	18.3%
METC	60	15	21.7%
FEM	54	19	35.2%
TIB	212	84	36.8%
METT	183	37	20.2%
METP	66	2	3.0%
Total	808	220	25.6%

Table 7: NR (Number of Remains), PM (Percussion marks) (NR and %)

	p-value		
	MUNG	LUNG	Total
Humerus	0.7863	0.3778	0.8295
Radio-Ulna	0.477	1	0.654
Metacarpal	0.3701	0	0.6418
Femur	0.2746	1	0.5062
Tibia	0.1977	0.5017	0.2111
Metatarsal	0.8685	0.1039	0.3492

Table 8: Fisher test results for the percussion marks distribution on diaphysis by portion.

We only observed a few impact marks on the articular portions (portions 1 and 5). This distribution is certainly due to the scarcity of the epiphyses in our sample, but it may also be related to a particular percussion strategies. For most of the long bones, all the surface of the shaft portions 2, 3 and 4 present impact marks (**S3**). Only three remains of both types of ungulate sizes bear double notches and thus highlighting the existence of counterblows, two right radio-ulnas of reindeer and one right tibia of megaceros.

Most of the notches are shallow (d1 or d2 depth). We identify micro-notches on nearly half of the percussion notches. Nearly the same proportion of micro-notches is observed for each type of depth (**S3**).

The proportion of percussion marks on medium-sized ungulates is closed to the proportion of large-sized class. For the large-sized ungulates, we recorded 22 percussion notches, which represents a third of the total long bone portions present for this sized-class. They are mostly present on tibias (14). We note a high diversity in location in term of portions and overall surfaces. For the medium-sized ungulates, 197 percussion notches are noted, which represents 27% of the long bone portions for that class. We could also observe a high dispersion of the percussion marks all along the diaphysis for all elements. Despite that, some recurrences may be highlighted, but rarely higher than 50% of the bone portions (**Figure 6**).

Humerus remains present a high proportion of percussion notches on the lateral side of each shaft portion. Radio-ulna elements have numerous percussion notches on the anterior side of the shaft portion 4. Metacarpals present a higher proportion of percussion notches on the lateral side of portion 2 and on the mesial side of portions 3 and 4. Femur remains show more notches on the anterior and lateral sides of portion 2 and on the posterior side of portions 3 and 4. Tibias present a high proportion of percussion notches on the anterior side of portion 2, on the anterior and posterior sides of portion 3 and on the lateral side of portion 4. Metatarsal remains present a high proportion of percussion notches on the mesial side of portions 2 and 3 and on the lateral, mesial and posterior sides of portion 4. Finally, only a few percussion marks were observed on the articular portions of tibias and metatarsals.

For the medium-sized ungulates, the frequency of scraping marks located in direct association with percussion marks is low for almost all the long bones (less of 10%), with the exception of the radio ulnas (20%) (**S3**). For the metatarsals no scraping marks is associated with percussion marks. For the large-sized ungulates, only two scraping marks are associated with percussion marks on femur and metatarsal.

Approche techno-culturelle de la fracturation des os longs chez les Néandertaliens (Sud-Ouest de l'Europe, MIS 5-3) : une systématisation des gestes ?

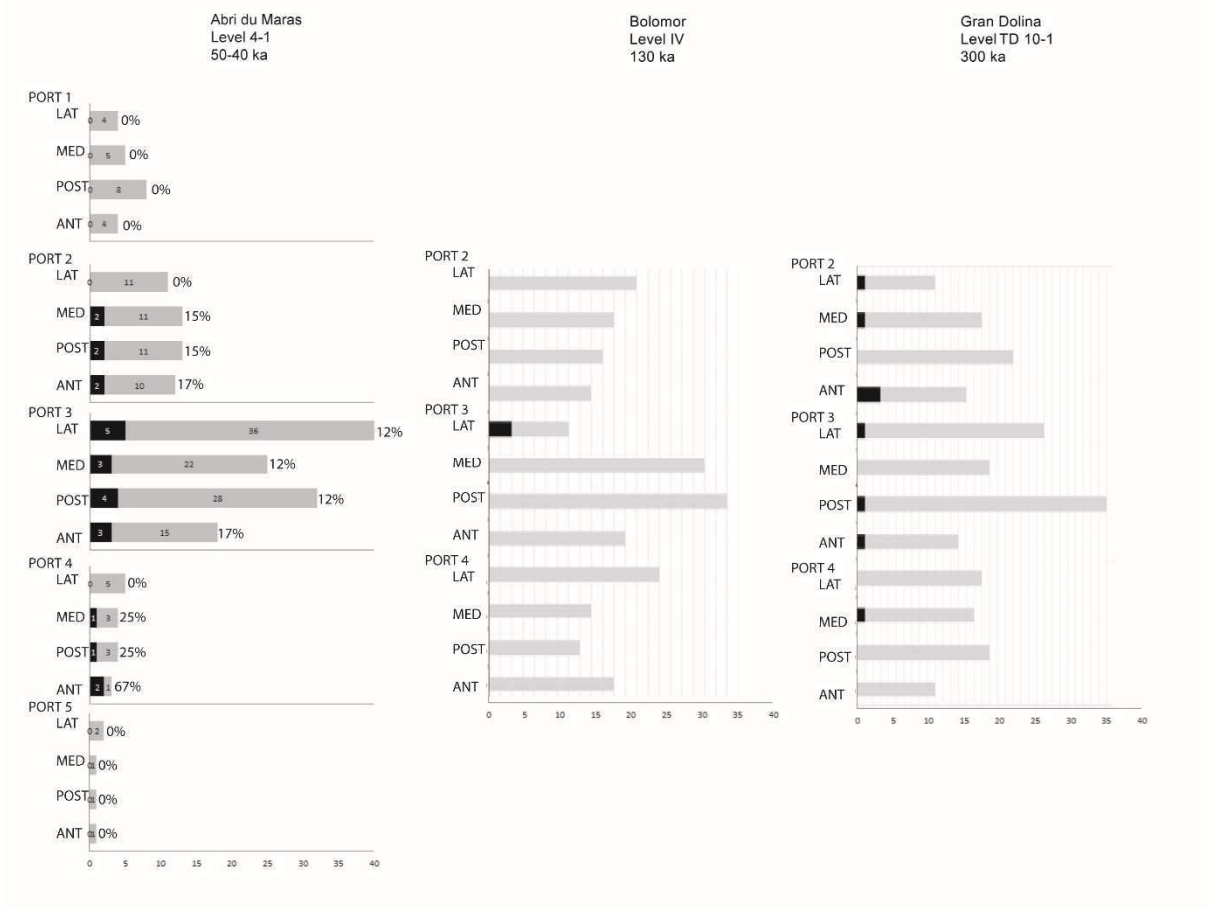
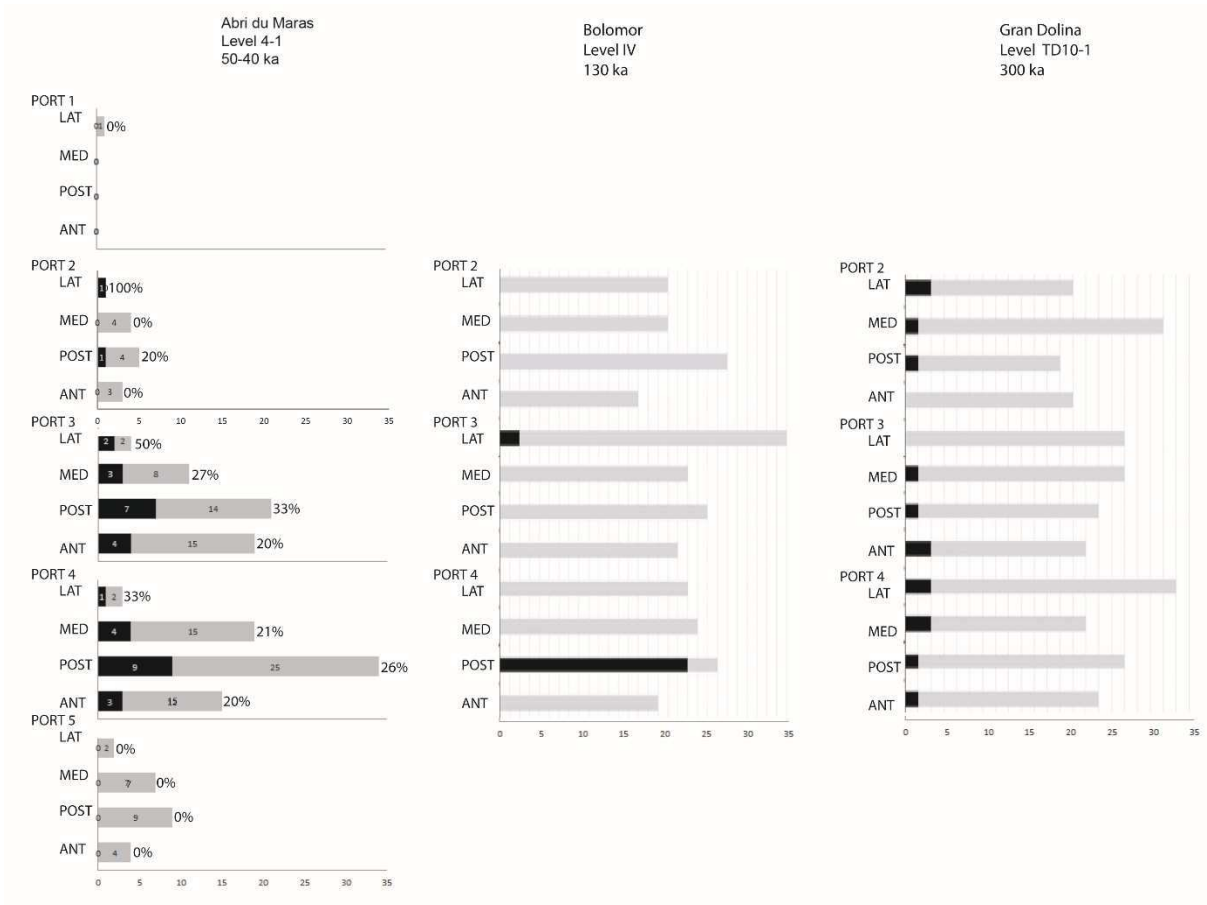




Figure 6: Relationship between the total of recovered bone portions and bone portions with impact notches from Abri du Maras level 4-1 (MUNG), Bolomor level IV and Gran Dolina level TD 10-1 (all class-sized) faunal assemblages by skeletal elements belonging to appendicular skeleton of ungulates.

The results of the Spearman correlation test show that the negative correlation between bone density and the location of the percussion marks within the long bone shafts (medium-sized ungulates) is not statistically significant ($\rho = -0.178$; $df = 17$; $t = 0.674$, $p > 0.05$).

Regarding tibia and metatarsal percussion marks for the medium-sized ungulates, they have a normal distribution. Inversely, the distribution on humeri, radio-ulnas, femurs and metacarpals does not follow a normal law. About large-sized ungulates, only percussion marks on tibias have a normal distribution. Regarding the totality of our sample, the distribution is homogenous only for tibias and metacarpals. Other long bones have a heterogeneous distribution of the percussion marks along their shafts.

In our sample, Fisher exact tests show that the distributions of percussion marks have not significant trends (**S4**) for both middle and large-sized ungulates and also taking into account all data. They are homogeneously dispersed on the diaphysis, and the differences observed are probably due to random for almost all the long bones in our sample.

Supplementary information 4

CA of humeri and tibias show that the individuals with the highest inertia on the first component are Bolomor level IV and Bolomor level XVIIc (**Figure 7**). On the second component Bolomor IV and experimentation by batting have the most inertia. For the radio-ulnas, CA show that on the first component we have individuals with highest inertia, the same as humeri and tibias, but on the second component, Bolomor level XVIIc and experimentation by batting are individuals with the most inertia. We observe on CA of femur that Bolomor level XVIIc and Abri du Maras are individuals contributing the most on the first component and on the second component these are Bolomor level XVIIc and level XVIIa.

5. Discussion: What long bone breakage can tell us about Neandertal technical practices at Abri du Maras?

Within the layer 4-1, long bones are highly fragmented and mostly from anthropic breakage. Green bone fractures predominate and length and circumference analyses confirm the great impact of anthropogenic processes on long bone fragmentation. This is also supported by the quasi-absence of carnivore marks and remains. Sediment pressure loading and frost action had not a significant influence as fragmentation factors. The only four complete long bones are all metapodials, bones which have a high volume of marrow. This abandonment could be explained

by an abundance of prey and the lack of necessity of additional fat or other events difficult to control archaeologically. The occupation of the layer 4-1 mostly occurred during autumn and zooarchaeological analyses highlight mass hunting episodes at that times, thanks to great seasonal reindeer migration (Daujeard, 2008; Daujeard and Moncel, 2010). This abundance of prey is also supported by the presence of anatomical connection, especially for the hind foot elements in this layer. Thus, in such a context of food profusion, Neandertals have abandoned some parts of animals, without intensively exploited them for their marrow. This had direct incidence on long bone breakage strategy, in term of systematic behaviour. Anyway, the long bone breakage at Abri du Maras layer 4-1 still appears quite intensive and suggests that Neandertals largely exploited the marrow as an important source of fat.

Large-sized ungulates have the highest rates of percussion marks by long bone portions, with almost a third of them. For the medium-sized ungulates, about a quarter of their long bone portions bear notches or impact flakes. For all type of ungulates, percussion marks are distributed throughout the diaphysis. The distribution does not seem to be related to the density of the bone portions or to any particular location. Indeed, statistical analyses show no systematic distribution of percussion marks along the shafts. Neandertals did not preferentially hit bones on the less dense parts of diaphyses, nor seem to have chosen a particular way of breakage. Indeed, the apparent percussion marks dispersion along the shafts at Abri du Maras 4-1 (beginning of the MIS 3) is comparable to that of Gran Dolina TD10-1 (MIS 9) and in some cases to the level XVIIa of Bolomor (**Figure 6**, Blasco *et al.* 2013). Their location close to zero on both axis of the factorial map of the CA also highlights that bones in these sites do not show preferential location of percussion marks (**Figure 7**). Inversely, specific patterns, in particular standardization and counter-intuitive gestures observed in the level IV of Bolomor (MIS 5e), were not identified at Abri du Maras. Indeed, we see that Bolomor level IV is far from the other series for all bone elements. In this site, percussion marks are rather localized close to distal posterior portion for humeri and tibia on lateral mid-shaft for radio-ulnas and on anterior mid-shaft for femurs. In Bolomor level XVIIc, percussion marks are close to distal posterior portion for humeri and to medial mid-shaft in femurs and tibias. On radio-ulnas, it is close to anterior mid-shaft, like for Bolomor level XVIIa.

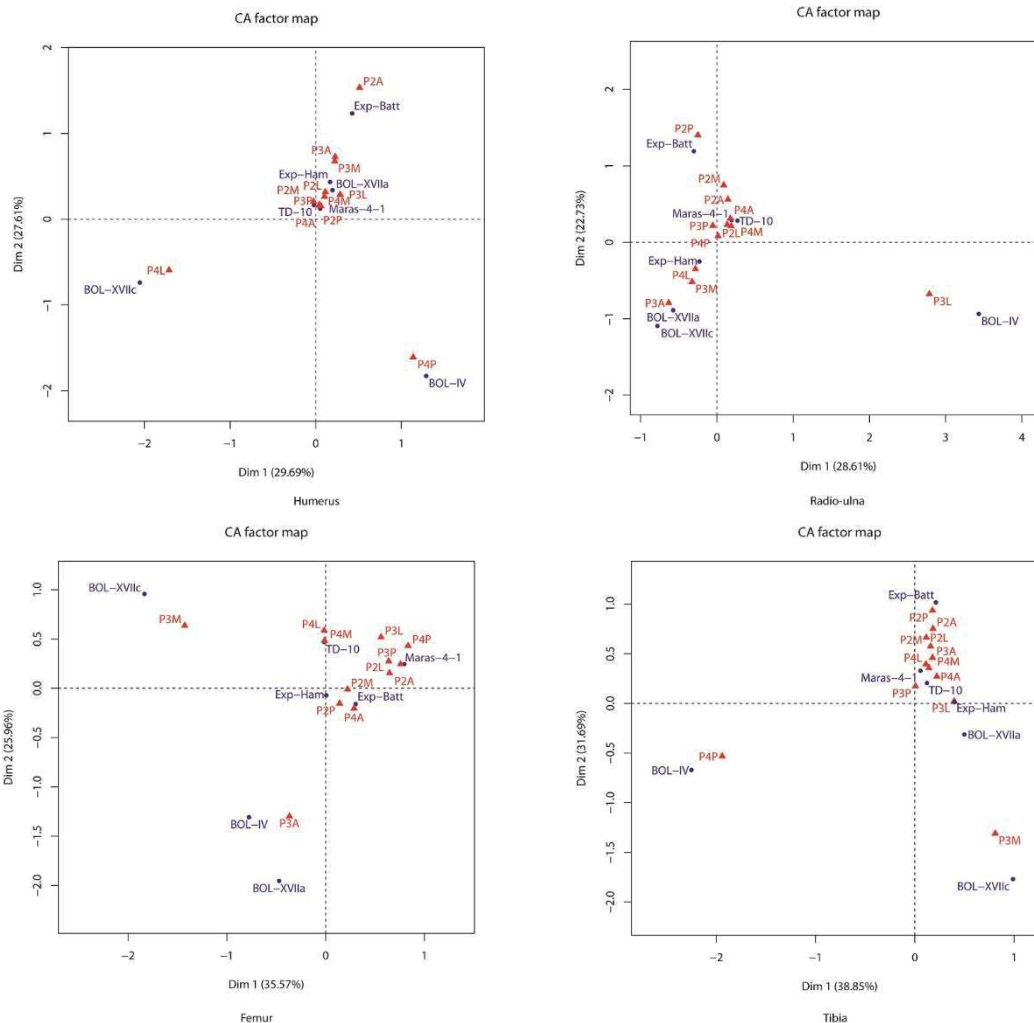


Figure 7 : Humerus, radio-ulna, femur and tibia correspondence analyses showing the location of the breakage marks on the bones (Anterior Portion 2 (P2A), Posterior Portion 2 (P2P), Lateral Portion 2 (P2L) and Medial Portion 2 (P2M) and the same for Portion 3 and Portion 4) in the sites of Maras level 4.1 (Maras-4-1), Bolomor level IV (BOL-IV), Bolomor level XVIIa (BOL-XVIIa), Bolomor level XVIIc (BOL-XVIIc) and Gran Dolina level TD 10-1 (TD-10) and for the experimentation with hammer stone (Exp-Ham) and experimentation by batting (Exp-Batt).

The graphs of CA show no particular pattern for the hammer-stone experimental methods (Figure 7). It seems to have some regularity for the batting method for the humeri, radio-ulnas and tibias. Non-trained experimenters may have hit those bones in the same way, holding them by the distal part. This pattern could result from a morphological choice –that is, an easier way to hold the bone. Blasco et al. (2014a, p.1087) reported that “all of the experimenters held the bones by the narrower end and hit them near the wider end following intuitive criteria, based on bone morphology and easiness/comfort of holding the skeletal element with the hands”. In this case, there was no specific manner to present bones to experimenters, thus the regularity of this bone breakage technique seems not to be associated with the experimental protocol. For femurs, the

batting method is much closed to distal anterior portion, but also closed to zero and not very significant. Anyway, the archaeological data for Abri du Maras, as well as the other fossil series, appear distant from the batting experimental methods. In case of a morphological choice, the batting method did not have to be used exclusively in any archaeological sites. The long bones were broken either by the hammer-stone method or by a mix of both, if individuals use an intuitive gesture.

In conclusion, we do not observe standardized breakage pattern at Abri du Maras 4-1 regarding the notches distribution along the shaft. That circumstance may respond here to two different hypotheses: 1) the presence of several groups bearing various butchery practices during the sedimentary formation and the marked palimpsest character of this layer or 2) the presence of individuals of one single group which do not share any butchery traditions.

Therefore, we have no proof of intergenerational transmission of a technical know-how as regards to the bone breakage practices at Abri du Maras and we certainly are in presence of occupations palimpsest by different cultural groups.

However, at the Abri du Maras, the autumnal reindeer mass predation could be a good indicator of the sharing of traditions between groups, including intergenerational transmission of the topographical and environmental knowledge for this shelter. Besides that, the preponderance of reindeer within our sample and throughout the layer 4-1, associated with recurrent autumnal occupations, clearly illustrates a choice by the occupants of the rock shelter (Daujeard and Moncel, 2010). The choice of the reindeer as the main meat resource may also signify that the group(s) using the shelter deliberately came for selective reindeer hunting (see discussion above). As most of them died during the autumn, they would have known the habitual migration routes of this gregarious species. These indicators could contribute to enhancing our understanding of the reasons for the choice of the site, located near a ford and the mouth of the Ardèche River. Given the recurrence of the occupations, it is thus possible to envisage that the localization and attributes of the site would have been passed on from one group to another or within the same group over several generations. Because the layer 4-1 is a palimpsest of several occupations, maybe more than thirteen (ash lenses), in this case the hypothesis of an intergenerational transmission of the site localisation and surrounding advantages could be proposed.

Concerning the lithic technology, the assemblages are composed of elongated Levallois flakes, flakes, points and cores and small flakes produced by small Levallois core on flakes on site (Moncel *et al.* 2014). The Levallois core technology is widely dominant in the series and

corresponds to the Levallois core technology observed at the MIS 4 and 3 in the area (mainly unipolar). The specificity of abri du Maras is the elongated and pointed end-products mainly used for the Late Middle Palaeolithic (Moncel et al., 2014) Neandertals occupying the Abri du Maras used mainly a Levallois technology that shows presence of one group or many groups sharing the same lithic practices. It seems that at Abri du Maras we observed the presence of an intergenerational transmission of knowledge for lithic technology. Moreover, the lithic strategies are coherent in this level and we cannot consider that, even if the series is the palimpsest of several occupations, the assemblage gather groups of different lithic traditions. The lithic series offers the opportunity to observe a tool kit which seems to be related to similar and recurrent activities performed at the site.

Whatever, several groups sharing the same lithic technology (Levallois) but with different butchery techniques could have met at Abri du Maras to conduct a mass predation during autumn.

We need a more fine-grained analysis of technical variability to identify more discrete spatial and temporal units, showing standardized patterns specific to certain regions or sites, to approach social entities. Identification of small-scale standardized patterns in both subsistence and technology opens an interesting avenue for future researches.

6. Conclusion

In our opinion, cutting incision does not seem to be the best way to analyse standardized butchery practices, mainly because of the influences of butcher dexterity, animal (morphology and size) and raw materials used, on the frequency and location of cut marks (Blasco *et al.* 2013). Indeed, cutting incisions in case of defleshing, disarticulating or even skinning may be very scarce when good and experimented butchers produce them. For example, in southeastern France, at the Early Middle Palaeolithic site of Orgnac 3, during the course of the sequence comprising ten occupation phases dating from MIS 9 to MIS 8, the rarefication of butchery striations in the levels at the top of the sequence would indicate improved butchery techniques, linked to increased dexterity (Moncel et al. 2012).

Inversely, scraping marks are intentionally made during the bone surface cleaning (removing the periosteum), and consequently do not depend on the dexterity of the butcher. They are thus a potentially significant source of information for the identification of butchering practices. Their study related to the analysis of percussion marks could bring additional

information to a better understanding of butchery tradition. In fact, at Abri du Maras, their frequency may indicate the recurrent use of certain breakage practices and thus the existence of a particular butchering culture.

In the same way, long bone breakage processes have already revealed their potential in the understanding of Neandertal butchery traditions (Blasco et al., 2013). Unfortunately, the results of this study for the layer 4-1 of Abri du Maras do not highlight specific butcher tradition in term of bone percussion strategies. We did not observe specific butchering practices that would have been shared by a same group returning several times in the site during the sedimentary filling. Due to the paucity of such studies and the rarity of comparative series, it is not currently possible to draw conclusions as to a possible chronological or geographical trend of cultural butchering traditions. Moreover, the big chronological gap existing between Gran Dolina TD-10 (upper part) and the two other sites, contemporaneous of the late Middle Palaeolithic, adds to this difficulty. For example, at Gran Dolina level TD 10-1, no hearth was found, contrary to the two other sites, where fire could potentially be used during the breakage process. However, we did not observe such practices in level 4.1 of Abri du Maras.

The question of identifying Middle Palaeolithic butchery traditions within Neandertal groups is central to a better understanding of intergenerational transmission practices. This research provides new data concerning the relation between meat consumption and the socio-cultural context of these human groups: learning of butchery techniques, systematization of gesture and dexterity in carcass processing. Based on a zooarchaeological study of faunal remains and specifically on the percussion marks analysis for the Middle Palaeolithic in Europe, it will be possible to test the hypothesis of the existence of various Neandertal butchery traditions at a large geographical scale, in parallel to technological traditions. It could be also possible to estimate the period and context (climate, environment, geographical area and type of human occupation) of the appearance of such a butchering know-how. For all that reasons, it seems necessary to increase the number of this type of study on many other Middle Palaeolithic sites. In the same way, to better take into account the impact of the animal size and morphology on carcass processing and specifically on bone fracturing, it will be also interesting to increase the experimental data corpus including various species.

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IV. 3. La standardisation de la récupération de la moelle osseuse : une approche techno-culturelle de la fracture osseuse au sein des groupes de Néandertaliens

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New evidence of butchery traditions within the Neandertal groups occupying Southwestern of Europe (MIS3-5)

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Abstract:

Long bone breakage is a commonly observed practice in Middle Palaeolithic contexts. Bone marrow, in particular, the yellow marrow contained in the medullary cavity of long bones was a valuable resource for Neandertals, whatever the climatic conditions. Butchering techniques, in the same way as lithic technology or tool types, provide innovative ways to define routines in human groups, and thereby to enhance our knowledge of traditions. Current research demonstrates that Neandertal groups applied intense standardized bone breakage, far removed from intuitive practice, related to bone density and/or skeletal morphology, as observed experimentally. These standardized patterns, which are systematic and counter-intuitive, were therefore interpreted as culturally induced. In this paper, we aim to test the hypothesis of butchery traditions among Neandertal groups and therefore of butchery cultural learning at three sites with large bone assemblages, located in south-eastern France and Northern Italy, dated to the Late Palaeolithic: Abri du Maras (MIS 4, Ardèche), Saint-Marcel (MIS 3, Ardèche), and Riparo Tagliente (MIS 4-3, Verona).

The detection of culturally-induced patterns involves differentiating them from intuitively generated patterns. To tackle this issue, we used a zooarchaeological approach focusing on the impact points produced during bone breakage processes. Then, our data were compared with other previously published zooarchaeological works focusing on butchery traditions, on one hand, and experimental studies focusing on the intuitive extraction of yellow marrow, on the other hand.

The Neandertal groups occupying levels 4.1 and 4.2 of the Abri du Maras applied diverse butchery traditions to recover the yellow marrow from humeri and femurs, for example. Likewise, at Saint-Marcel Cave, the groups occupying levels g and h seem to have developed a similar specific technique to extract yellow marrow. We highlight the diversity of standardized butchery practices on metatarsals at both French sites. However, in Riparo Tagliente, several groups or individuals of a same group, who did not share the same butchery traditions, probably occupied the site. Thus, the limits experienced are not only the number of remains but also the taphonomic alterations and statistical biases. Regarding the socio-cultural practices of Neandertal groups and the high degree of cognition, the existence of specific butchering traditions could be intricately interlinked with hunting strategies and the lithic technical culture. The diversity of traditional Neandertal behaviours should be considered by taking into account the practice of bone marrow recovery.

Keywords: Middle Palaeolithic, Neandertal, Long bone breakage patterns, Carcass processing, Cultural practices, Taphonomy

IV. 3. 1. Résumé long en français

Dans la continuité du travail sur la distribution des marques de percussion sur les os longs dans le niveau 4.1 de l'Abri du Maras, nous avons décidé d'augmenter le corpus de sites étudiés pour le Paléolithique moyen du Sud-Ouest de l'Europe. Cette région est composée de zones enclavées faites de bassins, de vallées et de plateaux. Ce paysage est différent de celui des grandes plaines du Nord de l'Europe, beaucoup plus ouvert. Nous avons sélectionné trois sites du Sud-Est de la France et du Nord de l'Italie datés du début du Pléistocène supérieur : l'Abri du Maras (MIS 3, Ardèche) ; la grotte de Saint Marcel (MIS 3, Ardèche) et Riparo Tagliente (MIS 4-3, Verona). Ces trois sites sont parfaitement adaptés pour tester l'hypothèse de la présence de traditions bouchères au sein des groupes néandertaliens. Ce sont en effet des accumulations quasi exclusivement humaines ; les surfaces osseuses présentent une bonne préservation ; les chaînes opératoires bouchères sont complètes et quasi-entièrement menées dans les sites et on observe dans tous une récupération systématique de la moelle par les Néandertaliens. Les spectres fauniques sont tous dominés par une espèce de cervidés : le cerf pour Saint-Marcel (niveaux g et h), le chevreuil pour Riparo Tagliente (niveaux 35 et 37) et le renne pour l'Abri du Maras (niveau 4.1), avec une exception dans le niveau 4.2 de ce site qui a livré un spectre faunique plus diversifié. Pour chacun des sites, afin de pouvoir mettre en évidence une possible évolution des pratiques bouchères au sein des séquences, nous avons sélectionné deux niveaux archéologiques provenant d'une même couche stratigraphique.

Cette analyse a été menée afin de répondre aux problématiques suivantes :

- Quel est l'impact des altérations taphonomiques sur l'identification et la caractérisation des marques de percussion ?
- Est-il possible de mettre en évidence l'existence de pratiques bouchères standardisées et contre-intuitive dans de nouveaux niveaux d'occupations néandertaliennes dans le Sud-Ouest de l'Europe ? Est-il possible de distinguer des traditions bouchères spécifiques selon les sites étudiés ?
- Est-il possible d'observer différences dans les traditions bouchères au sein d'une même séquence ?
- Est-il possible d'établir des liens entre les cultures lithiques, les stratégies de chasse et de boucherie et les traditions dans la fracturation osseuse chez les groupes néandertaliens des sites et des niveaux étudiés ?

Pour répondre à ces questions, nous avons sélectionné au sein de chaque niveau tous les os longs anatomiquement identifiés de la catégorie de taille dominante dans le spectre faunique.

Ce choix est lié en grande partie à la difficulté de différencier les espèces à partir des fragments d'os longs, et d'autant plus lorsque nous avons une majorité de diaphyses. La seule exception a été le niveau 4.2 de l'Abri du Maras où nous avons décidé d'établir deux échantillons distincts, séparant les grands et les moyens ongulés. Le spectre faunique de ce niveau est en effet dominé par les cerfs, les chevaux et les bisons (Chapitre II. 2. 1. 1.).

Nous avons donc analysé la distribution des marques de percussion sur les diaphyses dans chacune de nos séries et testé statistiquement si la répartition obtenue était aléatoire ou si elle était semblable au schéma de distribution intuitif issu de l'étude de notre expérimentation intuitive (Chapitre III. 3.).

Puis nous avons confronté nos résultats avec ceux obtenus dans les deux sites espagnols de : Bolomor (MIS 5) et de Gran Dolina (MIS 9) (Blasco et al., 2013).

A partir de la localisation des marques de percussion, nous avons donc pu mettre en évidence des tendances différentes de distribution pour certains éléments selon les sites et les niveaux, mais en revanche aucune systématisation dans l'emplacement des marques de percussion comme à Bolomor IV.

Avant de s'intéresser à la distribution nous avons décidé d'évaluer l'impact des différents agents taphonomiques sur l'enregistrement des marques de percussion. Nous avons pu mettre en évidence que les marques de percussion de surface tels que les *pits* ou les *grooves* sont les plus impactées par les altérations taphonomiques post-dépositionnelles. Nous avons donc suggéré de prendre en compte l'intensité des modifications taphonomiques dans le décompte de ces marques. Par ailleurs, la très grande rareté des épiphyses (conservation différentielle anthropique ou naturelle) pourrait expliquer l'absence de marques d'écrasement dans nos assemblages

L'absence de systématisation pourrait s'expliquer par des facteurs indépendants de l'extraction de la moelle jaune, comme par exemple la sur-fracturation des os longs pour l'extraction de la moelle rouge ou l'utilisation de la spongiosa comme combustible ou encore pour obtenir des supports d'industrie osseuse (retouchoirs). En effet, ces activités produisent des marques de percussion supplémentaires sans lien avec l'extraction de la moelle. Cependant, cette répartition aléatoire peut aussi s'expliquer par le passage de groupes différents avec des traditions bouchères distinctes ou par l'occupation du site par un seul groupe, mais au sein duquel les individus ont développé des savoir-faire différents.

Toutefois, la présence de tendances ou de zones plus impactées, permet de suggérer la présence de pratiques bouchères traditionnelles dans les sites de l'Abri du Maras et de Saint-

Marcel. A l'Abri du Maras, cette nouvelle approche a permis de distinguer dans le niveau 4.1 des distributions standardisées et contre-intuitives pour les humérus et les fémurs. Pour le niveau 4.2, ce sont les radio-ulnas des moyens ongulés et les humérus de grands ongulés qui semblent avoir bénéficié d'un traitement particulier. Cela suggère une différence de traitement qui serait fonction ici de la taille des animaux.

Pour Saint-Marcel, en prenant en compte les deux niveaux g et h, la distribution des marques de percussion des radio-ulnas permet de mettre en évidence des pratiques standardisées d'extraction de la moelle. En revanche, cette tendance disparaît lorsque les niveaux sont testés séparément. Cette différence observée suggère une tendance qui persisterait pour les deux niveaux, mais relativement faible et pourrait ne pas être discernable à l'échelle d'un seul niveau.

La répartition des marques sur les métapodes de l'Abri du Maras et de Saint-Marcel ne semble pas non plus aléatoire. Cependant, il n'existe aucun échantillon de comparaison expérimental pour ces os longs (Chapitre III. 2.), il ne nous est donc pas possible de faire des hypothèses pour savoir si ces os ont été traités de manière traditionnelle ou s'il s'agit de modèles intuitifs.

L'analyse complémentaire du test Exact de Fisher n'a pas mis en évidence de modèle de percussion privilégiant une zone de percussion particulière spécifique à un site. Néanmoins, nous avons identifié une exception : les métatarses de Saint-Marcel et de l'Abri du Maras ont montré des différences significatives du nombre de traces observées entre la zone p3a (Saint-Marcel) et p3l/p4l (Abri du Maras). Malgré l'absence de données expérimentales comparatives, pour les métatarses, nous pouvons suggérer la présence de traditions d'extraction de la moelle différentes entre ces deux sites.

Pour Riparo Tagliente, il ne nous a pas été possible d'avancer des hypothèses, à cause du nombre trop réduit d'ossements étudiés.

Les groupes de néandertaliens ayant occupés ces sites ont donc traité de manière standard certains os longs. Néanmoins, ce sont des éléments différents à chaque fois et cela ne nous apporte donc pas d'information sur une éventuelle spécificité entre les sites ou à l'échelle d'un même site.

La comparaison de la répartition des marques de percussion pour tous les sites combinés et pour les séries expérimentales en contexte intuitif, grâce à une analyse multifactorielle exploratoire (ACM) montre que, pour chaque élément osseux, les séries de Bolomor est presque toujours éloigné des autres séries.

La pratique traditionnelle de la récupération de la moelle osseuse est un des éléments structurant d'une réflexion plus globale sur les interactions sociales et la transmission intergénérationnelle. Ces traditions bouchères mettent en évidence des pratiques complexes au sein des groupes humains, pouvant diverger entre les niveaux d'un site ou encore montrer une certaine continuité des savoir-faire bouchers tout au long d'une séquence. Nos résultats peuvent-ils montrer une intrication des traditions lithiques, cynégétiques et bouchères ? En outre, nos résultats peuvent-ils être mis en perspective avec les réflexions sur la composition des groupes de Néandertalien afin de mieux comprendre leurs dynamiques socio-culturelles (Duveau et al. 2019) ?

IV. 3. 2. Publication n°5

New evidence of butchery traditions within the Neandertal groups occupying Southwestern of Europe (MIS3-5)

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specific technique to extract yellow marrow. We highlight the diversity of standardized butchery practices on metatarsals at both French sites. However, in Riparo Tagliente, several groups or individuals of a same group, who did not share the same butchery traditions, probably occupied the site. Thus, the limits experienced are not only the number of remains but also the taphonomic alterations and statistical biases. Regarding the socio-cultural practices of Neandertal groups and the high degree of cognition, the existence of specific butchering traditions could be intricately interlinked with hunting strategies and the lithic technical culture. The diversity of traditional Neandertal behaviours should be considered by taking into account the practice of bone marrow recovery.

Keywords: Middle Palaeolithic, Neandertal, Long bone breakage patterns, Carcass processing, Cultural practices, Taphonomy

Introduction

Over the last two decades, the diversity and flexibility of the Neandertal diet has been widely demonstrated [1–8]. The ability to use and to cook all the available resources in the environment suggests a combination of complex subsistence behaviours and opportunism [4]. Isotopic analyses show a dietary strategy based above all on animal protein [9–11]. In addition to the consumption of meat from large and small game, bone assemblages in Neandertal sites indicate widespread fat consumption. For example, red and yellow bone marrow were also an important food resource, especially in a dry and cold environment [12–15]. Due to the large accumulation of broken bones in Neandertal sites, focusing on the modalities of bone fracturing seems to be an innovative way of tracking traditional butchery practices among Neandertal groups [1,16–22].

Blasco et al. [23] applied, for the first time, the hypothesis of butchery practices to two Middle Palaeolithic Spanish sites (MIS 5-9): Bolomor (levels IV, IX, XIIa and XIIc) and Gran Dolina (TD10-1). They highlighted the presence of systematic and counter-intuitive percussion mark patterns in level IV of Bolomor, indicating specific butchery traditions. On the contrary, in the earlier level 10-1 of Gran Dolina, they could not demonstrate cultural know-how but brought to light a probable palimpsest combining various practices. After their innovative paper, some other analyses tried to demonstrate the existence of traditional butchery practices to recover yellow marrow in the Southern Mediterranean area [16,24].

Unlike percussion marks, cut marks did not permit to analyse standardized butchery practices, mainly because of the role of the butcher's dexterity, animal morphology and size, the raw materials and tools used, and the frequency and location of cutting incisions. Indeed, cut marks made during carcass processing may be very scarce for experimented butchers, whereas the direct percussion of long bones intentionally marks the bone element [14,25,26]. Indeed, cut marks made during the carcass processing may be very scarce when experimented butchers worked, whereas the direct percussion of long bones intentionally marked the bone element [16,23]. Besides, percussion marks are part of a complex "*chaîne opératoire*" where the bone can be considered both as a raw material for alimentary purposes and for tool production, i.e., bone retouchers or hammers for Neandertals [27–29].

For decades, analyses of Neandertal traditions were based on studies of lithic assemblages, which were assumed to record the characteristics of a group with the inter-generational transmission of knowledge [30–32]. Stone tools are even used as markers of a specific group or regional traditions. More and more, lithic analyses focus on the hypothesis that stone tool corpuses may indicate both activities and traditions. Regarding the analyses of faunal assemblages, the identification of traditions is mostly tested through studies of hunting strategies [20,33–36] while butchery techniques are very few studied.

In this paper, we consider that a butchery tradition is brought to light by observing standardized and counter-intuitive patterns showing that an inter-generational group share the same butchery know-how. Intuitiveness is the immediate apprehension of a non-trained butcher to break a bone. It could be influenced by anatomical constraints and other characteristics of the bone [23,37]. Some experiments focusing on the intuitive way to extract marrow highlighted intuitive patterns of percussion mark distribution [38].

Thus, the development of specific butchery skills, which could be applied to Neandertals who regularly broke long bones to extract yellow marrow, is a valuable hypothesis [39]. Hence, transmitted skills include habits enhanced by experience and/or group traditions. Butchery traditions imply know-how (sequences of gestures), dedication (time involved in the activity) and skill (ability to reproduce gestures and to correct them) [40]. Considering the degree of cognition, specific butchery traditions should be embedded in the socio-cultural practices of Neandertal groups, in the same way as hunting strategies and the cultural traditions of lithic tools. To test this hypothesis, we focus on three Neandertal sites with anthropogenic faunal accumulations; Abri du Maras and Saint-Marcel Cave in south-eastern France, and Riparo Tagliente in Italy. In order to monitor possible behavioural changes in butchery practices over time, we selected two layers

from each site, all dated between MIS 4 and 3 (Figure 1). We only focus on percussion mark distribution produced by yellow marrow recovery, after the evaluation of the impact of taphonomic alterations on the series.

The Middle Palaeolithic faunal assemblages of Abri du Maras, Saint-Marcel Cave and Riparo Tagliente are appropriate because they are almost exclusively anthropogenic accumulations, with a virtual absence of carnivore marks on bones. The faunal remains are well preserved and a complete butchery “*chaîne opératoire*” was conducted *in situ*. Moreover, the assemblages come mainly from recent excavations where all the bones were systematically recorded, including the smallest bone fragments. For almost all of them, the faunal spectrum is practically monospecific, with the predation of cervids (roe deer, red deer and reindeer), which is propitious to the comparison of hunting strategies. Our results are then compared with previous data published by [23] and with our own experimental data *e.g.*: [38].

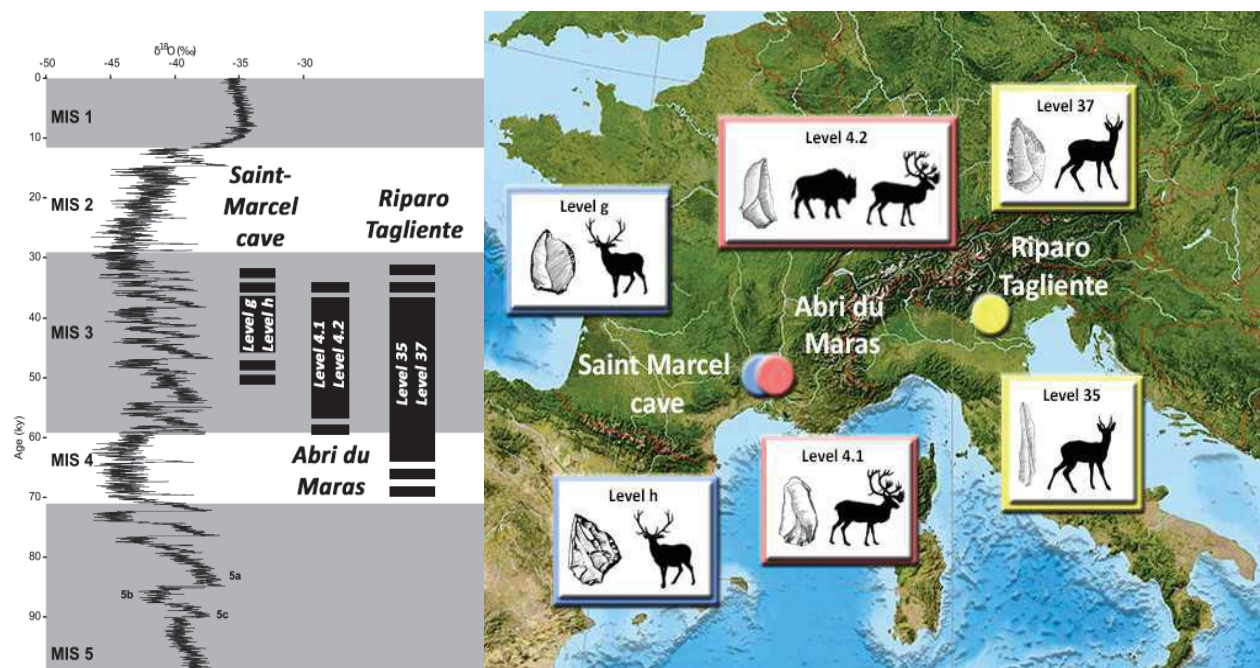


Figure 1: Location of the studied sites with the hunted species and an illustration of the lithic culture. Drawing by M. Arzarello, R. Gilles and A. Theodoropoulou.

Archaeological background

Abri du Maras layers 4.1 and 4.2

The site of Abri du Maras is located on the right bank of the Middle Rhône Valley, in a small dry valley of the Ardèche River, 70 m above the river. It constitutes the remains of a huge, former south-east facing rock shelter [17,41–43]

The first archaeological investigations revealed eight layers with Middle Palaeolithic deposits, with Levallois laminar debitage for layer 1 [41,44–46]. The new excavation only concerned the middle and lower parts of the sequence, from previously assigned layers 4 to 8. Stratigraphic unit 5 (layers 8-6 of the former excavations) was at the bottom of the sequence. The overlying unit 4 consisted of a silt and sandy-silty sedimentary accumulation (0.5 to 1 m thick), with two main phases of human occupations (4.1 and 4.2), with traces of combustion and occasional diffuse ash lenses. Unit 4 was excavated over an area of more than 50 m² [47]. There was no significant orientation of the material suggesting that no major disturbance of the archaeological remains occurred.

U/Th dating applied to bones from the top of unit 5/bottom of unit 4 yielded ages of 72 ± 3 ka, 87 ± 5 ky, 89 ± 4 ky, and 91 ± 4 ky [46,48]. New preliminary ESR-U/Th dating of ungulate teeth confirmed the chronology of unit 5 (90 ± 9 ky), but gave more recent ages for unit 4, attributed to MIS 3. Layer 4.1 (upper part of unit 4) thus dates to between 40 ± 3 ky and 46 ± 3 ky (n=2) (also MIS 3), while samples from layer 4.2 provided ages ranging from 42 ± 3 ky to 55 ± 2 ky (n=3) (MIS 3) [49].

The varied faunal spectrum for unit 4 was composed, in order of abundance, of *Rangifer tarandus*, *Equus ferus* cf. *germanicus*, *Cervus elaphus*, *Bison priscus*, *Capra ibex*, *Equus hydruntinus* and *Megaloceros giganteus* [17,42,50,51]. Carnivore remains were lacking. The identified fossil remains from layer 4.2 belonged, in order of abundance, to: perissodactyls (with more numerous *Equus ferus* than *Equus hydruntinus*), reindeer (*Rangifer tarandus*), as well as bison (*Bison priscus*), deer (*Cervus elaphus*), megaceros (*Megaloceros giganteus*), ibex (*Capra ibex*) and lagomorphs. Contrary to layer 4.1, layer 4.2 does not display a mono-specific spectrum [51]. Large ungulates were predominant (55.4%) and reindeer only represented a quarter of the hunted individuals. However, apart from the European ass, the same species were present in the faunal spectrum of both layers.

The lithic material represented in layer 4.1 totals 1,844 items and 1,647 items in layer 4.2. Lithic analysis revealed that the technical strategies applied mainly to flint and secondarily to other stones (quartz, quartzite and granite) involved the fragmentation of reduction processes into local

and semi-local perimeters around the site [47]. The main core technology is Levallois, discoidal and expedient, generally on cortical flint cores on flakes. Flint flakes, secondary blades and points are the main components. The largest flint flakes, Levallois blades and points were brought to the site from north and south of the site (up to 20-30 km away). Flake-tools are very rare (3% for layer 4.1 and 4.8% for layer 4.2), and never modified the shape of the pieces, except for one and two Quina scrapers made on a thick and wide flint flake.

In layer 4.1, 32 pebbles and in layer 4.2, 21 pebbles, mainly whole, but also broken or with a single removal, were introduced, possibly as hammerstones, although they bear few percussion marks. These quartz, quartzite, limestone, basalt, granite and rarely flint pebbles were collected in the surrounding rivers. They measure mainly between 60 and 120 mm and are round or oval.

The lithic analyses showed the anticipation of domestic needs for butchery, plant and woodworking [52]. Neandertals exploited a wide range of resources including large mammals, fish, ducks, raptors, rabbits, mushrooms, plants and wood. Evidence of impact fractures suggests that some points could have been used as projectile tips. They were either brought to the site as points or prepared on the site [52].

Saint Marcel cave layers g and h

The site of Saint-Marcel is located at the end of the Ardèche Gorge, not far from Grotte Chauvet, on the north side of the gorge, approximately 200 m inland from the Ardèche River. The deposits lie under the cave overhang, in a very large, sub-horizontal, south-facing section, 12.5 m wide, 7 m deep and 3 m high.

Excavations of the Mousterian layers were carried out by R. Gilles from 1974 to 1988, during which a surface area of 30 m² was exposed, reaching a depth of nearly 7 m. Two main stratigraphic units were defined. The upper one contains the twelve Mousterian occupation phases [41,53].

In all of the upper layers at Saint-Marcel, red deer represented more than 80 % of the number of identified specimens (NISP). Neandertals practised selective hunting of prime-aged adult deer [50,54,55]. Carcass butchery was particularly intensive. Butchery marks were recorded on just over half the identified specimens in the faunal assemblage and more than 70 % bore evidence of green-bone fractures. Topographical and zooarchaeological data showed that all of the layers were associated with long-term, large-scale occupation. In addition, the high proportion

of bone retouchers (n = 303, representing nearly 6 % of the total number of remains with a size superior to 5 cm (NR)) makes this site distinctive.

The lithic assemblages show marked homogeneity throughout the stratigraphic sequence. Flint, which was collected in various forms (as pebbles, nodules and tablets) was the main raw material used, and was procured from a variety of sectors (in the Barremian-Bedoulian from the plateau to the north, from the Orgnac plateau to the south and in the Rhone Valley to the east) [53,56]. The richest phase of occupation was between layers i and h, in the middle part of the sequence. A total of 4,982 lithic items were found at the site. Most of the flint processing probably took place at the site (the entire *chaîne opératoire* is represented). The lithic assemblage from all the layers consisted mainly of debitage products, especially flakes. These were small in size, ranging from 30 to 50 mm long, on average. They could mostly be attributed to discoid debitage (centripetal, unipolar or bipolar method), carried out especially on the ventral surface of flakes. In some cases, they strike along a third plane, resulting in the extraction of thick flakes with a triangular cross-section (“crested flake”) [53]. Very few retouched tools were found at this site (approximately 5%), consisting primarily of scrapers, in addition to some convergent pieces. Retouch was light and did not modify the blank, although some thinning is present.

For the other raw materials, the number of lithic objects is low (for instance n = 25 for layer h and n = 44 for layer g, 3.5%), and consists of some entire pebbles and above all pebble fragments/flakes in quartz, limestone and quartzite. Little evidence of the role of these raw materials was identified (remains of hammerstones or introduction of some flakes).

The lower layers (k to u) were attributed to MIS 5 based on the sedimentological analysis [41]. The paleontological analysis of the faunal remains clearly set layer u apart from all the others, given the abundance of fallow deer in this layer, with *Hemitragus cedrensis*, as well as a similar deer to that found at the site of Les Cèdres (Var, France). Both of these point to an Eemian occupation for layer u [57–59]. Paleontological, environmental and sedimentological analyses attribute Unit 7 (layers j to g) to a warm episode, either MIS 3 or the end of MIS 5 [41,50,54,55,60]. Given the hiatus in sedimentation between layers k and j, it was more likely that the upper part of the sequence dates to MIS 3. Given the hiatus in sedimentation between layers k and j, it is more likely that the upper part of the sequence dates to MIS 3 [41,61]. There seemed to be no hiatus in sedimentation between layers j and g, nor between g and f [41,50,54]. ¹⁴C results on bones from layer f [62] were statistically identical to each other: 37 850 ± 550 BP and 37 850 ± 600 BP. The third, 41 300 ± 1700 BP, overlaps them at two standard deviations. These results indicated that layer f of Saint-Marcel did indeed date to the late Mousterian.

Riparo Tagliente layers 35 and 37

Riparo Tagliente is a rock shelter located in the city of Stallavena di Grezzana (Verona, N-E Italy). It is located on the west slope of Valpantena, one of the main valley-bottom of the pre-Alpine massif of Monti Lessini at an altitude around 250 m. Situated at the bottom of a rock wall, it was formed by limestone stone, surrounding to the extent valley bottom [63–65].

The site was discovered in 1958 by Francesco Tagliente and excavated by the Museo di Storia Naturale di Verona from 1962 to 1964 [66–69]. In 1967, the University of Ferrara taken over the excavation of the site and pursue it until now. The systematic excavation provided an important stratigraphic series of deposit attributed to the Upper Pleistocene, within a high anthropic occupation [70].

Until the mid-seventies research focused mostly on the excavation of a long trench running transversally to the rock-shelter and on a test-pit located in the most internal area (Southern sector, Figure). Two archaeological units separated by a river escarpment were excavated. The lower unit was occupied during the MIS 4-3, this was characterized by Mousterian and Aurignacian lithic industries and an upper unit occupied during the Late Glacial, which provided an Epigravettian industry. The layer 35 and 37 belonged to the upper layers of the Mousterian deposit, characterised by loess sediment. Any radiometric dating was performed yet, the dating estimation of the upper unit was based on the analyses of the lithic and faunal assemblages [64].

Regarding the small mammals, the remains found were mostly teeth [64]. The assemblages of the upper Mousterian layer were dominated by *Microtus arvalis* but some species indicated, especially for the layer 37, a cold environment (*Microtus oeconomus*, *Microtus gregalis*, *Ochotona sp.* and *Sicista sp.*). While, in the layer 35 these species were replaced by species indicating a few increase of the temperatures (*Chionomys nivalis* and *Apodemus sp.*) [71].

The ungulates dominated the faunal spectrum of the two studied layers. *Capreolus capreolus* was the species the most represented, *Cervus elaphus*, *Capra ibex* and *Rupicapra rupicapra* are following regarding the Number of Remains. Among the few remains of carnivores, *Canis lupus* and *Ursus arctos* were the most represented. Few remains of *Marmota marmota* have been identified, whom a mandible with cut marks and few undetermined remains of *Aves* and only one of *Lepus sp.* The presence of foetal or neonatal cervid bones suggested an occupation of the rock shelter mainly during the spring [72,73]. Long bones constituted the majority of the faunal assemblage remains of the layer 35 and 37. Some isolated teeth and remains of axial element were identified. In addition, few tarsals and carpals were characterized and numerous phalanxes.

Within the layer 37, two teeth attributed to Neandertal species were identified [74].

In layer 37, the lithic material was constituted by a total of 18.379 items and the layer 35 of 9.164 items. The use of different reduction methods characterized the Mousterian sequence on local raw materials (chert). These cherts were collected in the neighborhood of the site. The opportunistic method was the best represented (c.f. S.S.D.A, [75]). Lithic analyses highlighted also the presence of discoid and Levallois method with the lineal and recurrent modalities, in the upper layers the unipolar recurrent became predominant [76,77]. The presence of a volumetric laminar debitage starting from layer 37 represented one of the main particularities of the lithic assemblage [77].

Very few cobbles has been found in the Mousterian layers and they all show percussion marks; they have consequently been interpreted as precursors. All pebbles are mostly spherical and have a diameter between 60 and 85 mm. They have been collected in the surrounding of the site and are mainly in quartzite (only one is on limestone). In the layer 35 any cobble has been found and in the layer 37, within the internal sequences, 3 pebbles have been found.

Material and Methods

Samples selection

The total Number of Remains (NR); the Number of anatomically Identified Specimens (NISPa); the Minimum Number of Elements (MNE); the Minimum Number of Individuals (MNI) and the Minimum Animal Unit (MAU) were the count indexes used in this work [14,25,78]. In addition, the MNE was calculated based on the count of the preserved areas (Figure 2) [16,23]. For purposes of the taxonomical and anatomical determination, we used both anatomical atlas and comparative collections located at the University of Ferrara and at the IPH (Institut de Paléontologie Humaine, Paris France) e.g., [79–81]. In addition, we based our determination on the works of E. Cregut-Bonnoure, N. Boulbes, N. Lateur and C. Daujeard (Abri du Maras and Saint Marcel cave) and Thun Hohenstein (Riparo Tagliente) [50,51,82]. Each identified faunal remains were grouped in three main size category: Large-sized ungulates (LUNG), Medium-sized ungulates (MUNG) and Small-sized ungulates (SUNG) [35,83] (Supplementary data 1).

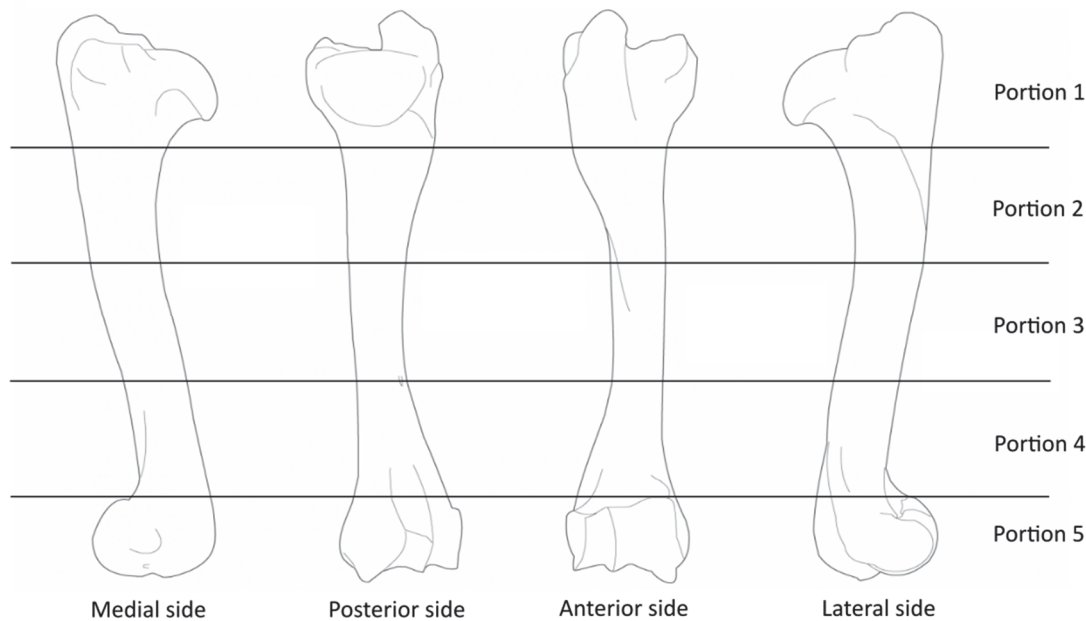


Figure 2: Example of the nomenclature used in the description of the bone portions and surfaces. Portion 1 (P1): proximal articular end; Portion 2: proximal diaphysis; Portion 3: medial diaphysis; Portion 4: distal diaphysis; Portion 5: distal articular end (after the drawing by Castel (2010), reference J. C. Castel (Geneva Museum) - © 2013 archéozoo.org).

We followed the methodology established by to analyse percussion mark distribution. Our work is a continuation of these papers, focusing on the comparison of percussion mark location on long bone shafts. For this reason, only long bone remains identified at least anatomically are taken into account, in order to accurately position percussion traces on bone. In our work, we distinguish long bone size categories for analytic purposes, i.e., SUNG, MUNG and LUNG. Within a given class size category, only samples with an MNE greater than 100 are selected.

For this study, we took into account the faunal assemblages from Abri du Maras (layers 4.1 and 4.2), Saint Marcel Cave (layers g and h) and Riparo Tagliente (layers 35 and 37). For the purposes of an intra-site comparison, we selected two relatively stratigraphically close layers from each site from the same unit. The layers chosen were highly anthropized, with butchery marks and the virtual absence of carnivore activity. The whole material represented more than 2,180 remains.

At Abri du Maras, the analysed material is from layers 4.1 and 4.2. The results concerning the percussion marks in layer 4.1 of the Abri du Maras were previously presented in [16]. For comparative purposes, we included the results relating to fragmentation, taphonomy and percussion mark location in the present analyses. We took into account the 742 anatomically identified MUNG remains. The faunal spectrum for layer 4.1 of the Abri du Maras was largely

dominated by the reindeer and therefore the MUNG [51]. Reindeer remains also predominated the faunal spectrum for layer 4.2. Nevertheless, the remains of bison, horse and red deer are better represented in the faunal spectrum than in layer 4.1. Regarding the number of remains for each class, we included both MUNG and LUNG remains, and we divided this assemblage into two different samples named 4.2LUNG and 4.2MUNG. They constituted respectively 39% and 51% of the Number of taxonomically Identified Specimens (NISPt). The sample from this layer provided 570 remains, including 203 4.2LUNG and 367 4.2MUNG.

The studied material comes from layers g and h of Saint Marcel Cave. These two layers were dominated by the MUNG, in particular by the red deer (layer g: $\text{NISPt}_{\text{MUNG}}$ 91% of the $\text{NISPt}_{\text{Total}}$; layer h: $\text{NISPt}_{\text{MUNG}}$ 87% of the $\text{NISPt}_{\text{Total}}$) [50]. [50]. For this reason, we chose our sample in this size category. Our analyses were carried out on 258 remains from layer g and 303 long bone remains from layer h.

The studied material from Riparo Tagliente comes from layers 37 and 35. Most of the sample consists of roe deer for both layers and is completed by ibex and chamois remains (layer 37: $\text{NISPt}_{\text{SUNG}}$ 44% of the $\text{NISPt}_{\text{Total}}$; layer 35: $\text{NISPt}_{\text{SUNG}}$ 90% of the $\text{NISPt}_{\text{Total}}$). SUNG long bone remains dominated the faunal assemblages of these layers. Therefore, we took into account 176 SUNG remains from layer 35 and 138 remains from layer 37.

Taphonomy

The cortical surface of each remain was observed with the naked eye and a 15-20x lens, under low-angled light. When necessary, a stereomicroscope (Leica S8 APO 10-80x) was used for the identification and recording of bone surface modifications. Different taphonomical alterations (edaphic and biologic) were recorded based on the criteria identified in the scientific literature e.g., [14,25,84–89]. In order to identify the impact of taphonomical alterations, we recorded which part of the cortical surface was altered by each physico-chemical taphonomic modification, following [50]. More specifically, for each alteration modifying the surface of the fragment, we attributed a scale code from 0 to 3. The code was 3 when the alteration covered the entire bone surface. The code was 2 if more than half of the entire bone surface was modified. If less than half the surface was affected, the code was 1. Finally, if no modification was observable to the naked eye, the code was 0. Taking into account all the alterations, we noted that cortical surfaces could be completely dissolved or concreted until they were illegible. Therefore, illegible remains were also counted for each assemblage. We compared the different surface modifications for the studied sites and layers.

We paid special attention to anthropogenic modifications, and in particular to percussion marks. Burnt damage was also recorded [90]. We divided the cut marks into two categories, according to the criteria established by [91]; incisions and scraping marks. We excluded the illegible remains from the percentages of the cut mark analysis. In the studied faunal assemblages, long bones with retouched areas were recorded, and again, the illegible remains were excluded from the percentages. They were identified based on recent works setting out new criteria [29,92–94].

Bone The long bone fragmentation of our assemblages was compared in terms of length. Each layer assemblage was divided into size classes as outlined above. These classes were 0–25 mm, 26–50 mm, 51–75 mm, 75–100 mm, 101–125 mm, >125 mm, bone part (complete epiphyses) and whole bones [95]. We measured the three dimensions (length, width, thickness) for each element. According to their size and circumference, we categorized the shaft fragments [96]: $l_1 < 1/4 \leq l_2 < 1/2 \leq l_3 < 3/4 \leq l_4 = 1$ (complete) and $0 < C_1 < 0.5 \leq C_2 < 1; C_3 = 1$ (complete). Based on fracture features, we distinguished between post-depositional and green bone fractures [95,96]. When possible, the taphonomic fragmentation factor was also specified, such as gelifraction, for example.

The percussion marks were recorded following the terminology of Vettese et al. (submitted): crushing marks, notches, adhering flakes, pits and grooves. In this work, we did not include flakes because it was virtually impossible to locate them precisely on the long bone shaft. In order to identify preferentially impacted areas, each identified fragment was positioned in an area according to its long bone portion and side (Figure 2). Some bone fragments could be identified on the basis of an anatomical particularity, such as the metatarsal gutter, but it was not possible to locate precise areas. In such cases, they were excluded from percussion mark distribution analyses.

The number of areas preserved by element varies according to the studied faunal assemblages. Therefore, we weighted the number of areas with percussion marks with the number of areas preserved for each area. The percussion mark ratio is calculated by:

$$\text{Number of areas with percussion marks} / \text{Number of preserved areas.}$$

Experimental data

For the purposes of comparison, we included experimental data from three major experiments [23,37,38]; Vettese et al. (in prep.). The main aim of these experiments was to record

percussion mark location when novice experimenters broke bones to extract the yellow marrow. The analysis of percussion mark distribution along the long bone shaft provided data on intuitive patterns. These three experiments enable us to compare two different species (cow [23] and Vettese et al. in prep] and red deer [37]) and the technique used to break the bones. Indeed, some experimenters used the hammerstone on anvil technique [23,37,38]; (Vettese et al., in prep.) while the rest of them used the batting technique ([23]and Vettese et al. in prep). The analyses conducted to record percussion mark distribution were similar to those applied to the archaeological samples, presented above.

Data analysis

We used an alpha of 0.05 for all the tests. Spearman's rho was used to test the correlation between long bone density indexes and percussion mark frequency by portion to test whether the densest parts or the least dense zones were the most impacted. Bone density indexes were estimated by [25] and [97] LUNG for *Equus*, MUNG for *Cervus* and SUNG for *Ovis*. We also employed this bivariate test to cross the %MAU and the medullary cavity volume of ungulate long bones to explore human carcass transport strategies [98]. Finally, we tested the correlation between the number of percussion marks per element with its NISPa to determine whether the number of identified fragments affected the number of percussion marks recorded per element. The correlation coefficients and tests were computed using R software [99].

The chi-square test of independence was employed to verify whether percussion mark locations are non-randomly distributed along the diaphysis or not. The chi-square test of conformity was used to verify if the observed distributions are similar to intuitive butchery distribution.

Multiple Correspondence Analysis (MCA) was used to investigate the relationship between the impacted and non-impacted bone portions (the three diaphyseal portions) and bone sides and to examine whether butchery patterns could be identified for specific sites and/or levels and bone elements. Therefore, the site, the level and the bone elements are displayed as illustrative variables. MCA was computed using the FactoMineR [100] package in R. When Cochran's rules were not respected, we used Fisher exact tests with R to test the independence between the location of impacts on the long bone shafts of each assemblage according to the different long bones. When necessary, pairwise multiple testing was performed. In such cases, the Holm correction of multiple testing was applied to the p-values.

In the MCA, our samples were compared with archaeological samples from Bolomor (IV, XVIIa, XVIIc) and Gran Dolina (TD-10-1 [upper part]) and with four experimental series [23,37,38], Vettese et al. (in prep)). The comparison of the results of [23] with two Middle Palaeolithic Spanish sites (MIS 5-9): Bolomor (levels IV, IX, XIIa and XIIc) and Gran Dolina (TD10-1), enables us to test the use of a standardized method for recovering marrow. Their results highlighted the presence of percussion mark patterns in Bolomor (level IV), indicating specific butchery traditions. On the contrary, in level 10-1 of Gran Dolina, the study did not demonstrate the presence of a tradition. We compared all the long bones. Metapodials were absent in the experimental samples, therefore, the comparison of these elements was only carried out for the archaeological samples.

Results

Taphonomic preservation of the bone samples

Bone surface preservation

The taphonomic alterations affect our various bone assemblages differently (Table 1), but these alterations are usually similar within a same sequence. The vast majority of the long bone surfaces of Saint Marcel and Riparo Tagliente are legible, while one-third of the bone surfaces are illegible at Abri du Maras in both layers. This illegibility derives mainly from root etching dissolution, and in some cases prevents the identification of cut marks, areas used as bone retouchers or percussion pits. Notches are not usually affected by surface illegibility. Bone cracking is recorded on all the assemblages. Concretions affect bone surfaces to a lesser extent, in particular at Abri du Maras layer 4.2 and Riparo Tagliente.

Concerning animal-induced modifications, carnivore remains, digested elements and carnivore or rodent tooth marks are either scarce or inexistent in all the sites. The site of Riparo Tagliente is the most affected with only three elements with carnivore marks and five carnivore remains [16,50,72].

Sites Layer	Saint Marcel cave			Riparo Tagliente			Abri du Maras			4.2M					
	NR	%	h	NR	%	37	NR	%	4.1	NR	%	4.2L	NR	%	
Cracking	f0	146	56.59%	198	65.35%	88	63.77%	104	59.09%	452	60.92%	20	9.85%	75	20.44%
	f1	112	43.41%	105	34.65%	31	22.46%	53	30.11%	247	33.29%	59	29.06%	160	43.6%
	f2	50	19.38%	69	22.77%	14	10.14%	12	6.82%	40	5.39%	65	32.02%	93	25.34%
Concretion	f3	4	1.55%	27	8.91%	5	3.62%	7	3.98%	3	0.4%	59	29.1%	39	10.63%
	c0	226	87.60%	241	79.54%	112	81.16%	110	62.5%	646	87.06%	17	8.37%	63	17.17%
	c1	30	11.63%	47	15.51%	18	13.04%	56	31.82%	85	11.46%	157	77.34%	281	76.57%
Dissolution	c2	2	0.78%	15	4.95%	6	4.35%	8	4.55%	11	1.48%	29	14.29%	23	6.27%
	c3	0	0%	0	0%	2	1.45%	2	1.14%	0	0%	0	0%	0	0%
	s0	185	71.71%	222	73.27%	26	18.84%	59	33.52%	18	2.43%	2	0.99%	6	1.63%
Blunting	s1	58	22.48%	68	22.44%	110	79.71%	114	64.77%	281	37.87%	26	12.81%	93	25.34%
	s2	23	8.91%	13	4.29%	2	1.45%	3	1.7%	267	35.98%	75	36.95%	144	39.24%
	s3	0	0%	0	0%	0	0%	0	0%	166	22.37%	100	49.26%	124	33.79%
Desquamation	b0	208	80.62%	189	62.38%	117	84.78%	135	76.7%	688	92.72%	98	48.28%	232	63.22%
	b1	44	17.05%	103	33.99%	9	6.52%	3	1.7%	51	6.87%	79	38.92%	124	33.79%
	b2	6	2.33%	11	3.63%	0	0%	0	0%	3	0.4%	26	11.8%	11	3%
Root etching	b3	0	0%	0	0%	0	0%	0	0%	0	0%	0	1%	0	0%
	d0	207	80.23%	251	82.84%	72	52.17%	51	28.98%	206	27.76%	40	19.70%	91	24.8%
	d1	35	13.57%	44	14.52%	95	68.84%	69	39.20%	170	22.91%	108	53.20%	151	41.14%
Black coloring	d2	14	5.43%	8	2.64%	8	5.80%	18	10.23%	200	26.95%	45	22.17%	100	27.25%
	d3	2	0.78%	0	0%	1	0.72%	0	0.00%	166	22.37%	10	4.93%	25	6.81%
	r0	0	0%	0	0%	35	25.36%	81	46.02%	29	3.91%	4	1.97%	13	3.54%
Orange coloring	r1	0	0%	0	0%	102	73.91%	94	53.41%	246	33.15%	33	16.26%	96	26.16%
	r2	0	0%	0	0%	1	0.72%	1	0.57%	270	36.39%	80	39.41%	160	43.6%
	r3	0	0%	0	0%	0	0%	0	0%	197	26.55%	86	42.36%	98	26.7%
Total	Black coloring	0	0%	0	0%	116	84.06%	159	90.34%	590	79.51%	183	90.15%	331	90.19%
	Orange coloring	0	0%	0	0%	80	57.97%	119	67.61%	365	49.19%	82	40.39%	139	37.87%
	Illegible	2	0.78%	1	0.33%	5	3.62%	4	2.27%	180	24.26%	87	42.86%	123	33.51%
Total	258	100%	303	100%	138	100%	176	100%	742	100%	203	100%	367	100%	

Table 1: Bone surface modifications (NR and τ) with for each of them the stages of surface modifications for each level of each site.

Long bone element distribution and differential bone preservation

The number of each long bone element varies according to the layers and ungulate class-size. The %MAU of the long bones of Riparo Tagliente is the highest since almost all the elements have a ratio superior to 50% (Table 2). Tibias are the most abundant long bones for all the assemblages, except in layer 4.1 (Abri du Maras), where metatarsals are the most frequent (Figure 3). Radio-ulnas, with the exception of AM-4.2LUNG, are also numerous.

The %MAU of each element in relation to each layer and marrow cavity volume (ml) are not significantly correlated (Spearman correlation: $df = 5$; $p\text{-value} > 0.05$). On the contrary, the %MAU and bone density are significantly positively correlated for: Abri du Maras, series 4.1 and 4.2MUNG; Saint-Marcel Cave g and h (Spearman correlation: $df = 25$; $p\text{-value} < 0.01$; $r_s < 0.01$) and Riparo Tagliente layer 35 (Spearman correlation: $df = 25$; $p\text{-value} = 0.01$; $r_s = 0.45$). No significant correlation is noted for layer 37 of Riparo Tagliente and the 4.2LUNG assemblage of Abri du Maras (Spearman correlation: $df = 25$; $p\text{-value} > 0.05$).

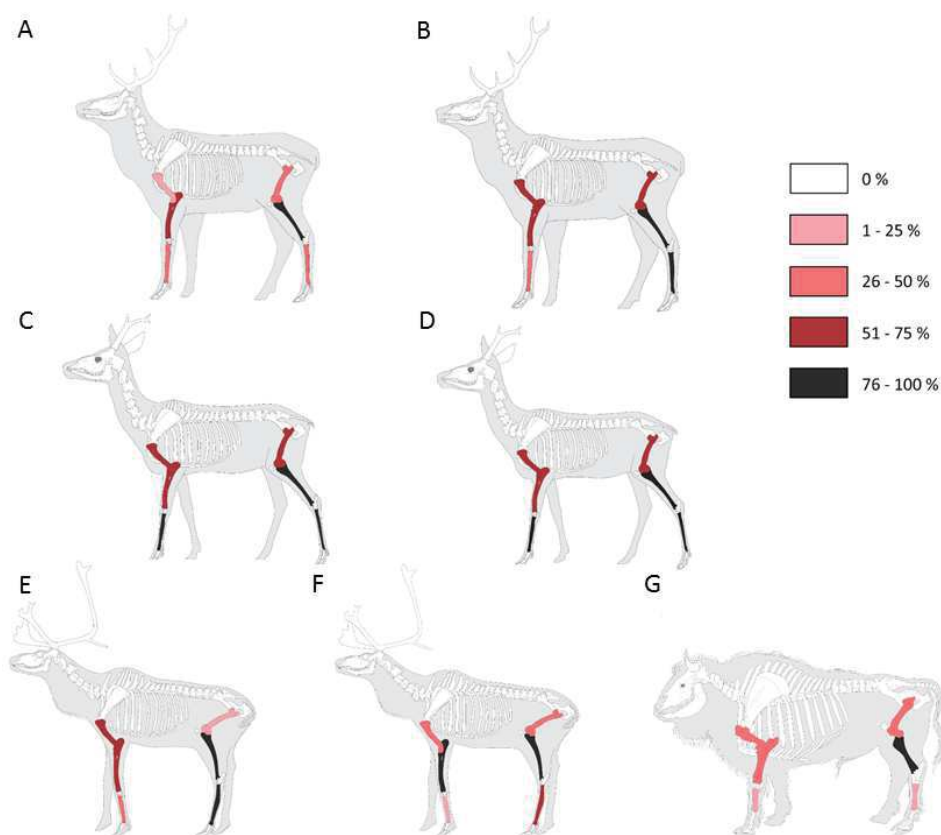


Figure 38: % MAU of the element for each series: A- Saint Marcel g, B- Saint Marcel h, C- Riparo Tagliente 35, D- Riparo Tagliente 37, E- Abri du Maras 4.1, F & G- Abri du Maras 4.2.

Sites	Element	NISPa	% NISPa	Right	Left	juv	NME	% NME	MAU	% MAU	Max (mm)	Min (mm)	Mean (mm)	SD
Abri du Maras Layer 4.1 MUNG	Humerus	97	13%	32	40	0	34	18%	17	55%	123	23	54.89	17.91
	Radio-ulna	123	17%	34	32	1	41	21%	20.5	66%	193	22	59.64	26.36
	Metacarpal	58	8%	13	14	2	19	10%	9.5	31%	181	16	60.25	34.07
	Femur	45	6%	8	12	0	17	9%	8.5	27%	110	28	61.44	21.66
	Tibia	184	25%	53	58	3	41	21%	20.5	66%	166	16	63.52	24.6
Total	Metatarsal	167	23%	24	33	2	62	32%	31	100%	150	16	56.91	25.07
	Metapodial	68	9%	1	1	3	11	6%	5.5	18%	101	16	45.19	20.92
	Total	742		165	190	11	225		112.5		193	16	57.41	25.1
	Humerus	41	11%	13	21	0	20	12%	10	44%	130	32	62.66	21.92
	Radio-ulna	79	22%	16	11	0	43	26%	21.5	96%	177	23	62.09	31.75
Abri du Maras Layer 4.2 MUNG	Metacarpal	23	6%	1	10	0	8	5%	4	18%	171	21	71.09	27.6
	Femur	32	9%	10	10	0	15	9%	7.5	33%	105	26	72.41	32.54
	Tibia	95	26%	32	40	2	45	27%	22.5	100%	161	34	76.97	36.1
	Metatarsal	72	20%	10	7	0	29	17%	14.5	64%	219	23	59.77	23.89
	Metapodial	25	7%	1	0	1	8	5%	4	18%	105	35	60.16	18.64
Total	Total	367		83	99	3	168		84		219	21	66.9	29.88
	Humerus	32	16%	11	11	0	16	16%	8	35%	147	48	92.06	23.92
	Radio-ulna	29	14%	3	3	0	13	13%	6.5	28%	240	41	100.59	46.03
	Metacarpal	6	3%	0	4	0	4	4%	2	9%	245	52	134	28.99
	Femur	29	14%	7	6	0	14	14%	7	30%	149	27	95.93	33.85
Abri du Maras Layer 4.2 LUNG	Tibia	93	46%	25	35	1	46	47%	23	100%	309	28	101.67	49.13
	Metatarsal	8	4%	1	1	0	3	3%	1.5	7%	132	39	77.88	34.25
	Metapodial	6	3%	0	0	0	2	2%	1	4%	114	26	78	39.88
	Total	203		47	60	1	98		49		309	26	98.52	42.49

Sites	Element	NISPa	% NISPa	Right	Left	juv	NME	% NME	MAU	% MAU	Max (mm)	Min (mm)	Mean (mm)	SD
Saint-Marcel Layer g MUNG	Humerus	18	7%	12	6	2	9	8%	4.5	2.4%	119	39	69.89	20.06
	Radio-ulna	41	16%	21	14	1	24	20%	12	65%	157	30	88.68	28.59
	Metacarpal	31	12%	7	9	0	13	11%	6.5	35%	143	33	71.81	29.69
	Femur	32	12%	12	10	2	16	13%	8	43%	149	36	88.88	28.07
	Tibia	64	25%	18	35	0	37	31%	18.5	100%	181	38	92.82	29.89
	Metatarsal	47	18%	6	12	1	18	15%	9	49%	156	32	76.71	27.52
Metapodial	25	10%	3	3	3	3	3%	1.5	8%	159	9	77.56	28.82	
Total	258	79	30%	12	89	7	120	13%	60	60%	181	9	88.09	29.34
Saint-Marcel Layer h MUNG	Humerus	30	10%	12	14	1	17	13%	8.5	52%	138	39	73.06	23
	Radio-ulna	43	14%	19	19	1	17	13%	8.5	52%	137	34	73.58	25.89
	Metacarpal	45	15%	7	7	2	13	10%	6.5	39%	128	30	72.02	22.42
	Femur	36	12%	14	14	0	18	14%	9	55%	154	29	82.31	29.43
	Tibia	60	20%	18	31	6	33	25%	16.5	100%	157	43	88.95	25.18
	Metatarsal	76	25%	19	19	0	33	25%	16.5	100%	150	29	80.66	29.17
Metapodial	13	4%	0	2	2	1	1%	0.5	3%	121	22	62.38	21.18	
Total	303	89	29%	12	104	12	132	17%	66	66%	157	22	79.48	27.01
Riparo Tagliante Layer 37 SUNG	Humerus	18	10%	9	4	0	9	17%	4.5	82%	65	19	59.6	9.65
	Radio-ulna	13	7%	9	2	2	6	12%	3	55%	75	31	51.79	13.76
	Metacarpal	33	19%	4	3	0	9	17%	4.5	82%	75	14	42.38	14.21
	Femur	22	13%	4	10	0	5	10%	2.5	45%	55	22	42.86	13.75
	Tibia	39	22%	15	16	2	11	21%	5.5	100%	99	29	50.23	16.24
	Metatarsal	30	17%	2	2	2	10	19%	5	91%	95	14	41.38	15.99
Metapodial	21	12%	1	1	1	2	4%	1	18%	64	19	41.67	16.98	
Total	176	43	24%	37	5	52	29%	26	26%	99	14	44.45	15.21	
Riparo Tagliante Layer 35 SUNG	Humerus	18	13%	6	5	0	11	13%	5.5	69%	56	26	40.5	12.35
	Radio-ulna	5	4%	4	1	0	9	10%	4.5	56%	74	18	51.63	18.42
	Metacarpal	32	23%	4	3	2	16	19%	8	100%	88	14	39.31	13.58
	Femur	15	11%	1	2	2	11	13%	5.5	69%	77	25	38.72	11.26
	Tibia	20	14%	9	7	0	16	19%	8	100%	89	25	57.48	19.2
	Metatarsal	39	28%	1	2	2	15	17%	7.5	94%	85	14	37.46	17.2
Metapodial	9	7%	0	0	0	8	9%	4	50%	73	15	40.67	12.55	
Total	138	25	18%	4	20	4	86	62%	43	43%	89	14	42.86	16.64

Table 2: Number of anatomically Identified Specimen (NISPa), Left (L) and Right (R) sides, Number of Indeterminate Remains (ind), Number of Remains belonging to juveniles (juv), Minimum Number of Element (MNE), Minimum Animal Unit (MAU), maximal length (Max), minimal length (Min) mean size of long bones (Mean) and standard deviation (SD).

Bone breakage

All the long bones series are highly fragmented. No complete bones were found at Riparo Tagliente and Saint Marcel. At Abri du Maras, we only identified one complete reindeer metacarpal in layer 4.2, and three reindeer metapodials and a horse metacarpal in layer 4.1 [16]

Shaft fragments are very well represented for all the studied series (Table 3). The epiphysis-diaphysis ratio is 0.17 (323/1917). The scarcity of epiphyses could be explained by numerous factors, such as differential conservation, anthropogenic breakage to recover bone grease or the use of bone spongiosa as fuel [101–104].

	Abri du Maras			Saint Marcel cave		Riparo Tagliente	
	4.1	4.2 L	4.2 M	g	h	35	37
Epiphyse	162	27	31	25	41	13	24
Diaphyse	888	196	282	282	273	109	169
E/D	0.182	0.138	0.110	0.089	0.150	0.119	0.142

Table 3: Number of epiphysis and diaphysis long bone portions and ratios of epiphysis on diaphysis (E/D).

Regarding the dimensions of bone fragments, most of the remains are between 25 mm and 100 mm long (Table 4, Supplementary data 3). In addition, we note a differential fragmentation rate according to ungulate class size. None of the 4.2LUNG remains from Abri du Maras is smaller than 25 mm in length, whereas the SUNG remains from Riparo Tagliente are the most abundant for this length interval. The SUNG remains from Riparo Tagliente 35 and 37 are never longer than 100 mm while almost 50% (89/203) of the remains from Abri du Maras 4.2LUNG are greater than 100 mm long.

Sites Layer	Saint Marcel cave				Riparo Tagliente				Abri du Maras					
	g		h		35		37		4.1		4.2L		4.2M	
	NR	%	NR	%	NR	%	NR	%	NR	%	NR	%	NR	%
Green bone fracture	252	97.67%	283	93.4%	136	98.55%	163	92.61%	682	91.91%	192	94.58%	358	97.55%
Dry bone fracture	71	27.52%	152	50.17%	34	24.64%	20	11.36%	222	29.92%	53	26.11%	75	20.44%
Und. fracture	2	0.78%	4	1.32%	9	6.52%	16	9.09%	88	11.86%	45	22.17%	61	16.62%
Gelifraction	0	0%	0	0%	5	3.62%	0	0%	17	2.29%	8	3.94%	38	10.35%
0-25	1	0.39%	2	1%	18	13%	11	6%	38	5.12%	0	0%	6	1.63%
25-50	31	12.02%	34	11%	74	54%	100	57%	299	40.3%	14	6.9%	109	29.7%
50-75	75	29.07%	109	36%	39	28%	59	34%	250	33.69%	42	20.69%	143	38.96%
75-100	84	32.56%	91	30%	7	5%	6	3%	117	15.77%	58	28.57%	64	17.44%
100-125	42	16.28%	44	15%	0	0%	0	0%	31	4.18%	46	22.66%	27	7.36%
>125	25	9.69%	23	8%	0	0%	0	0%	7	0.94%	43	21.18%	18	4.9%
25<NISP<100	190	73.64%	234	77%	120	87%	165	94%	666	89.76%	114	56.16%	316	86.10%
NR burnt	40	15.50%	107	35.31%	7	5.07%	4	2.27%	10	1.35%	1	0.49%	1	0.27%
NR Cut marks	175	68.36%	166	54.97%	64	48.12%	91	52.9%	211	37.54%	59	50.86%	83	34.02%
NR Percussion marks	146	56.59%	136	44.88%	56	40.58%	69	39.2%	197	26.55%	77	37.93%	112	30.52%
NR Retoucher	23	8.98%	37	12.25%	8	6.0%	11	6.40%	0	0%	5	4.31%	6	2.46%
NR Total	258	100%	303	100%	138	100%	176	100%	742	100%	203	100%	367	100%

Table 4: Frost, green, dry and indeterminate long bone breakage (NR and τ); measurement intervals along the length of the long bone (NR and τ); anthropic alteration and marks (NR and τ).

No complete bone circumferences were preserved for bone fragments. For all the series, the majority of the remains have a c1 circumference and a l1/l2 length (figure).

Fracture profiles are mainly curved/V-shaped with oblique angles and smooth edges. Thus, green bone fractures are the most numerous, affecting more than 90% of the number of the studied remains for each layer. Dry bone fractures are recorded on approximately 25% of all samples. The number of indeterminate fractures varies from one site to another from 1 to 22%. Gelifraction is a minor factor in the fragmentation of bone assemblages, and only appears at Abri du Maras and Riparo Tagliente layer 35.

Anthropic activity

Cut marks are the best represented anthropogenic marks in our assemblages, followed by percussion marks (Table 4). We recorded the lower cut mark rates in layers 4.1 and 4.2 of Abri du Maras than in the other sites. In most of the layers of Riparo Tagliente and Saint-Marcel Cave, we identified cut marks on more than 50% of the identified fragments.

For the Abri du Maras and Riparo Tagliente samples, the number of burnt remains is very low (< 5%). However, in these two sites, we observe numerous indeterminate burnt splinters [82]. At Saint-Marcel, burnt elements are more abundant, with percentages between 15 to 35% among our samples (Table 4).

With the exception of layer 4.1 of Abri du Maras, where no retouchers were identified, in the other studied samples their number varies according to the layers (Table 4). Saint-Marcel Cave is the site with the most bone retouchers (between 9 and 12%). At Riparo Tagliente, despite the predominance of small ungulates, percentages are around 6%.

Percussion marks analysis

Percussion marks type

Notches are the predominant percussion marks for the studied samples, followed by pits. Adhering flakes and grooves are the least numerous. Crushing marks are totally absent from our assemblages (Table 5).

In the Abri du Maras assemblages, all the percussion marks are notches, but we also observed pits of ovoid morphology and adhering flakes. A slightly higher number of pits and adhering flakes was identified for 4.2LUNG layer than for layer 4.1. No grooves were observed (Table 5).

In the Saint-Marcel series (Table 5), around two-thirds of the percussion marks are notches and around a quarter are pits. The rate of adhering flakes and grooves is lower, at around 10%. Most of the notches, in both layers, are conchoidal and a minority present an internal triangular pit or groove. Triangular percussion pits are more numerous in both layers.

In the Riparo Tagliente layers, grooves and adhering flakes constitute around 1% of all percussion marks. Again, notches are the most numerous type of marks identified. They are all conchoidal whereas a minority identified in layer 35 present an internal triangular pit or a groove. Pits are the second most represented type of mark, generally with an ovoid morphology (Table 5).

Site Layer	Saint Marcel cave				Riparo Tagliente				Abri du Maras					
	g		h		35		37		4.1		4.2L		4.2M	
	NR	%	NR	%	NR	%	NR	%	NR	%	NR	%	NR	%
Notch	171	67.6%	151	62.4%	58	65.9%	90	84.1%	218	99.5%	93	95.9%	144	97.3%
triangular	21	12.3%	25	16.6%	6	10.3%	0	0%	0	0%	0	0%	0	0%
ovoïde	150	87.7%	126	83.4%	52	89.7%	90	100%	0	0%	94	101%	144	100%
Pit	59	23.3%	69	28.5%	29	33.0%	16	15.0%	1	0.5%	4	4.1%	2	1.4%
triangular	32	54.2%	57	82.6%	9	31.0%	7	43.8%	0	0%	0	0%	0	0%
ovoïde	27	45.8%	12	17.4%	20	69.0%	9	56.3%	1	100%	4	100%	2	100%
Groove	2	0.8%	5	2.1%	1	1.1%	0	0%	0	0%	0	0%	0	0%
Crushing marks	0	0%	3	1.2%	0	0%	0	0%	0	0%	0	0%	0	0%
Adhering flake	21	8.3%	17	7%	0	0%	1	0.9%	0	0%	10	10.3%	2	1.4%
Percussion marks	253		242		88		107		219		97		148	

Table 5: Number of percussion marks by layer of the studied sites, by type of percussion mark.

The number of percussion marks by elements

At Abri du Maras, the three series show a relatively similar distribution of percussion marks per element (Table 6). One third of the percussion marks are situated on tibias, while only a few percussion marks were identified on metacarpal remains. More specifically, for layer 4.2LUNG, none of the metatarsal remains present percussion marks. Percussion marks are equally represented for the other long bones.

Similarly, at Saint-Marcel Cave, percussion mark distribution is equivalent per element for both levels. Tibias and metapodials are the most impacted fragments.

For the Riparo Tagliente layers, tibias and metapodials are also the bone elements with the most marked areas.

Site Layer	Saint Marcel cave				Riparo Tagliente				Abri du Maras					
	g		h		35		37		4.1		4.2L		4.2M	
	NR	%	NR	%	NR	%	NR	%	NR	%	NR	%	NR	%
Humerus	23	9.1%	22	9.1%	10	11.4%	25	23.4%	44	20.1%	22	22.7%	19	12.8%
Radio-ulna	40	15.8%	23	9.5%	3	3.4%	3	2.8%	24	11.0%	11	11.3%	26	17.6%
Metacarpal	61	24.1%	47	19.4%	19	21.6%	15	14%	14	6.4%	3	3.1%	8	5.4%
Femur	26	10.3%	26	10.7%	13	14.8%	14	13.1%	21	9.6%	26	26.8%	15	10.1%
Tibia	55	21.7%	38	15.7%	12	13.6%	25	23.4%	77	35.2%	34	35.1%	56	37.8%
Metatarsal	31	12.3%	78	32.2%	29	33%	22	20.6%	37	16.9%	0	0%	20	13.5%
Metapodial	17	6.7%	8	3.3%	2	2.3%	3	2.8%	2	0.9%	1	1.0%	4	2.7%
Percussion marks	253		242		88		107		219		97		148	

Table 6: Number of percussion marks by layer of the studied sites by element.

The number of percussion marks and NISPa by element are significantly positively correlated in the following assemblages: Abri du Maras 4.2LUNG (Spearman correlation: p-value = 0.032, $r_s = 0.82$) and 4.2MUNG (Spearman correlation: df = 6, p-value < 0.01, $r_s = 0.96$); Saint Marcel cave level h (Spearman correlation: df = 6, p-value = 0.007, $r_s = 0.93$) and Riparo Tagliente 35 (Spearman correlation: df = 6, p-value = 0.012, $r_s = 0.86$). In the other assemblages, they were not significantly correlated (Abri du Maras, 4.1; Saint Marcel Cave, g and Riparo Tagliente, 37: Spearman correlation: df = 6, p-value > 0.05). In terms of the whole assemblages of each site, only Saint Marcel Cave showed a positively significant correlation between these variables, while the Abri du Maras and Riparo Tagliente faunal assemblages did not show a correlation (Spearman correlation: df = 6, p-values > 0.05).

The percussion marks frequency by bone areas

None of the studied assemblages or long bones show a systematic distribution of percussion marks, i.e., only one or two struck areas (Figure 4, 5, 6, 7, 8 and 9). The number of areas with at least one percussion mark varied between two and 14 areas per bone element. Thus, in order to identify tendencies, we took into account frequencies equal to or higher than 0.33 and counted their occurrence per element, so that we could carry out inter- and intra-site comparisons. The lateral side of the medial portion (p3l) of the humerus shows higher proportions in five faunal assemblages (layers g, 35, 37, 4.1 and 4.2MUNG, 71.4%) (Figure 4). We record high frequencies for the femur in five series on the proximal portion (p2l) of the lateral side (layers g, h, 35, 4.1 and 4.2LUNG; 71.4%) (Figure 7). For the radio-ulna, the most impacted area is the anterior side of the distal portion (p4a) (layers g, h, 4.1 and 4.2LUNG; 42.9%) (Figure 5). For the

metacarpal, we identified two areas with high frequencies of impact traces: the lateral side of the proximal portion (p2l) and the medial side of the medial portion (p3m), for three of our samples (layers g, h, and 4.1 and layers g, 4.1 and 4.2MUNG; 42.9%) (Figure 6). On the metatarsal, five areas were identified. Two tibia series do not show high frequencies (Saint-Marcel Cave layer g and Abri du Maras layer 4.2LUNG) (Figure 9). For the others, only 28.5% show a tendency with higher frequencies. The areas with higher frequency tendencies are always located on the diaphysis. Within the same site, the most impacted areas do not systematically display similar locations. The frequencies of the impacted portions and long bone density indexes are not significantly correlated for each series (Spearman correlation: $df = 25$; $p\text{-value} > 0.05$).



Figure 4: Frequencies of number of percussion marks by portion on humerus of each sample (% and Number of area with percussion mark(s) / Number of area preserved); Saint Marcel cave level g (A), level h (B); Riparo Tagliante level 35 (C), level 37 (D); Abri du Maras level 4.1 (E), level 4.2 LUNG (F), level 4.2 MUNG. The absence of portion in each assemblage is grey.

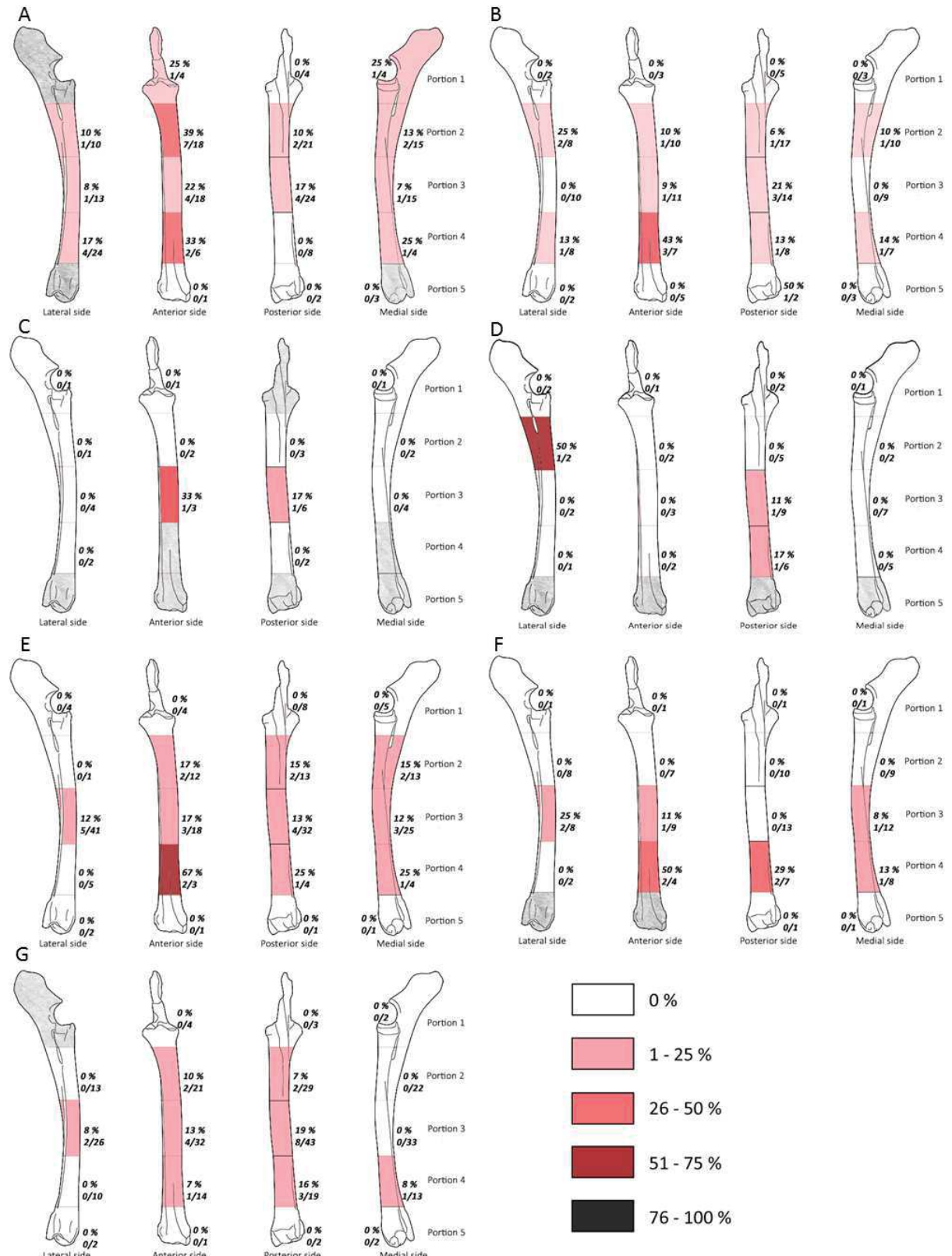


Figure 5: Frequencies of number of percussion marks by portion on radio-ulna of each sample (% and Number of area with percussion mark(s) / Number of area preserved); Saint Marcel cave level g (A), level h (B); Riparo Tagliante level 35 (C), level 37 (D); Abri du Maras level 4.1 (E), level 4.2 LUNG (F), level 4.2 MUNG. The absence of portion in each assemblage is grey.

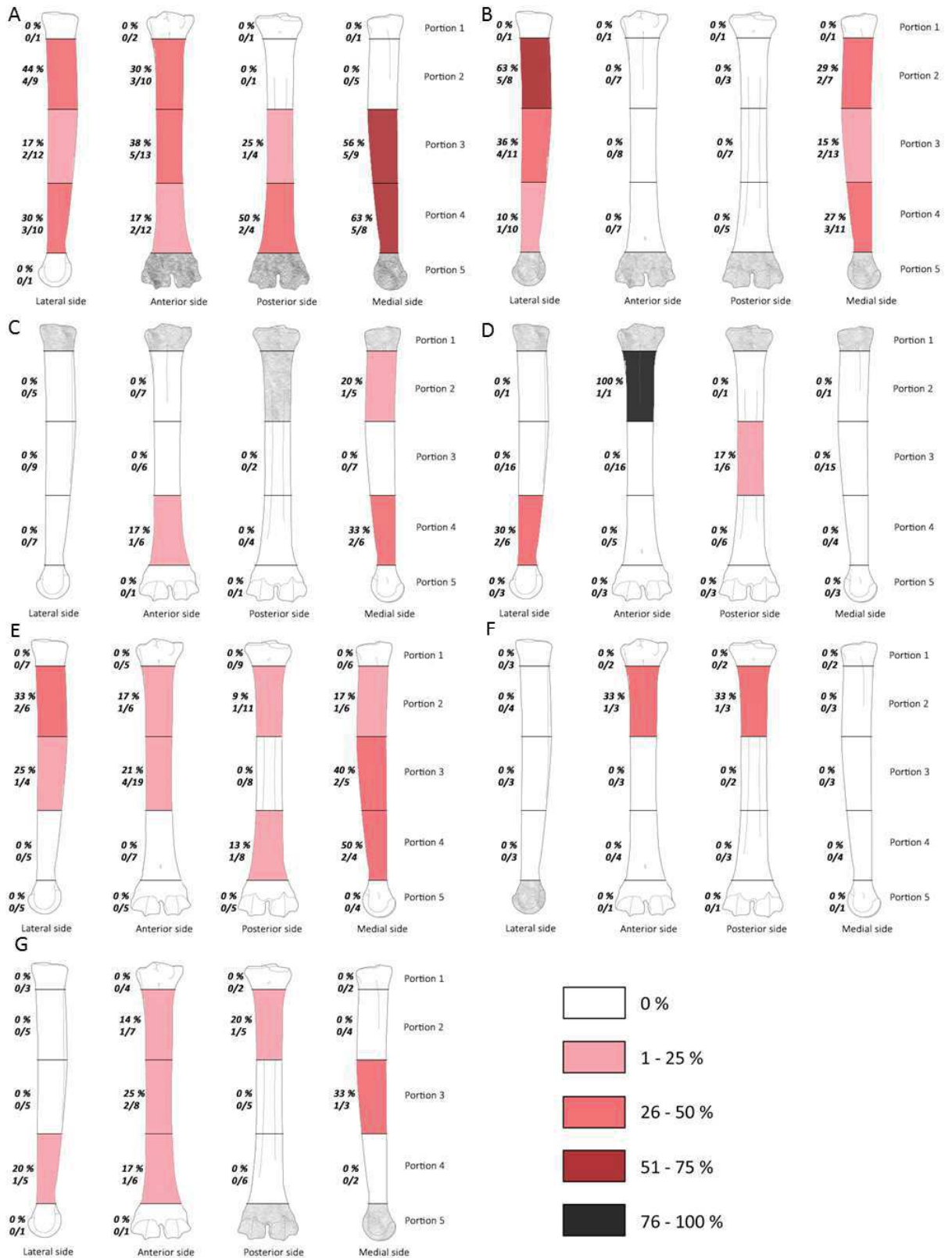


Figure 6: Frequencies of number of percussion marks by portion on metacarpal of each sample (% and Number of area with percussion mark(s) / Number of area preserved); Saint Marcel cave level g (A), level h (B); Riparo Tagliante level 35 (C), level 37 (D); Abri du Maras level 4.1 (E), level 4.2 LUNG (F), level 4.2 MUNG. The absence of portion in each assemblage is grey.



Figure 7 : Frequencies of number of percussion marks by portion on femur of each sample (% and Number of area with percussion mark(s) / Number of area preserved); Saint Marcel cave level g (A), level h (B); Riparo Tagliente level 35 (C), level 37 (D); Abri du Maras level 4.1 (E), level 4.2 LUNG (F), level 4.2 MUNG. The absence of portion in each assemblage is grey.

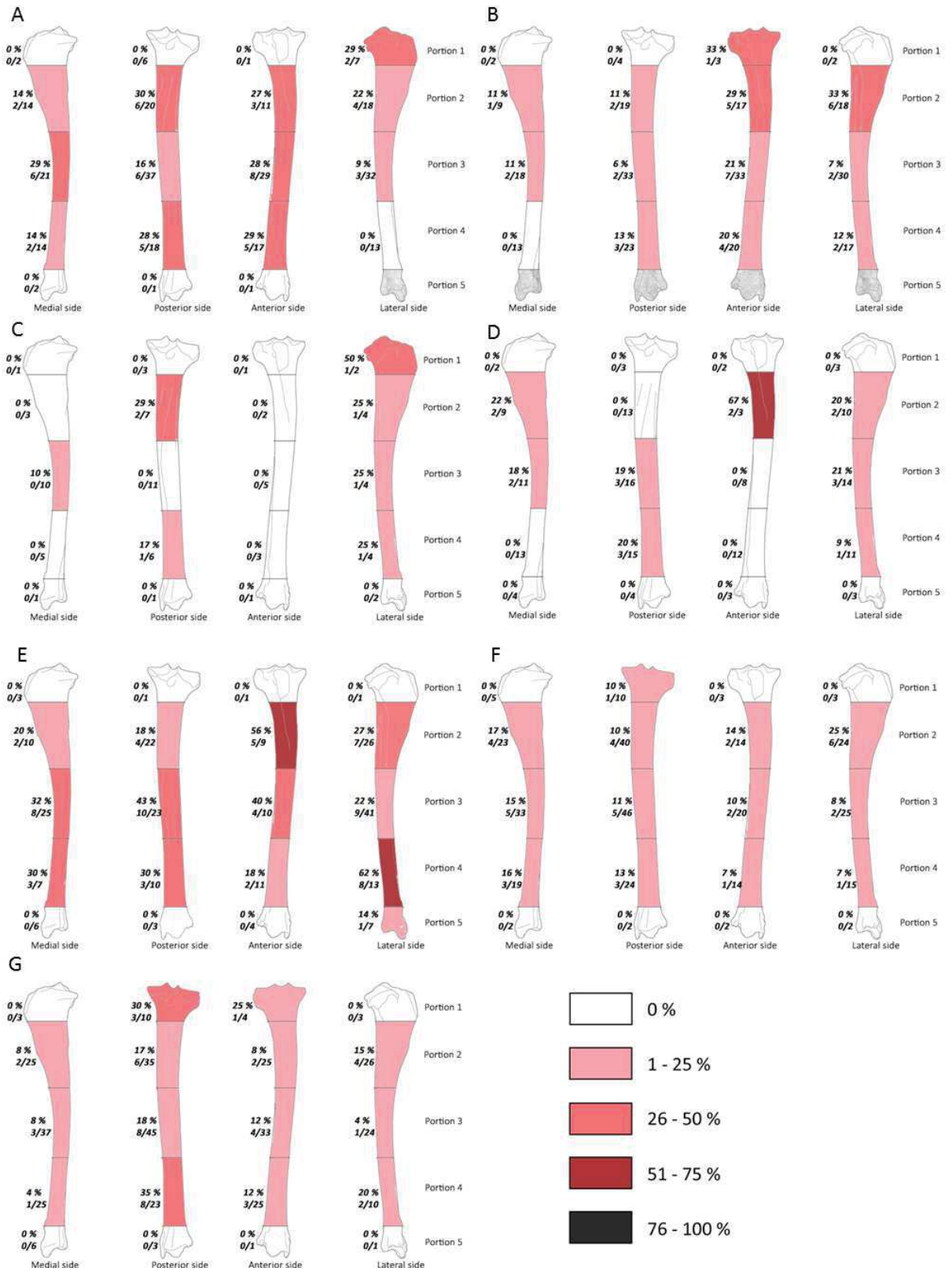


Figure 8: Frequencies of number of percussion marks by portion on tibia of each sample (% and Number of area with percussion mark(s) / Number of area preserved); Saint Marcel cave level g (A), level h (B); Riparo Tagliante level 35 (C), level 37 (D); Abri du Maras level 4.1 (E), level 4.2 LUNG (F), level 4.2 MUNG. The absence of portion in each assemblage is grey.

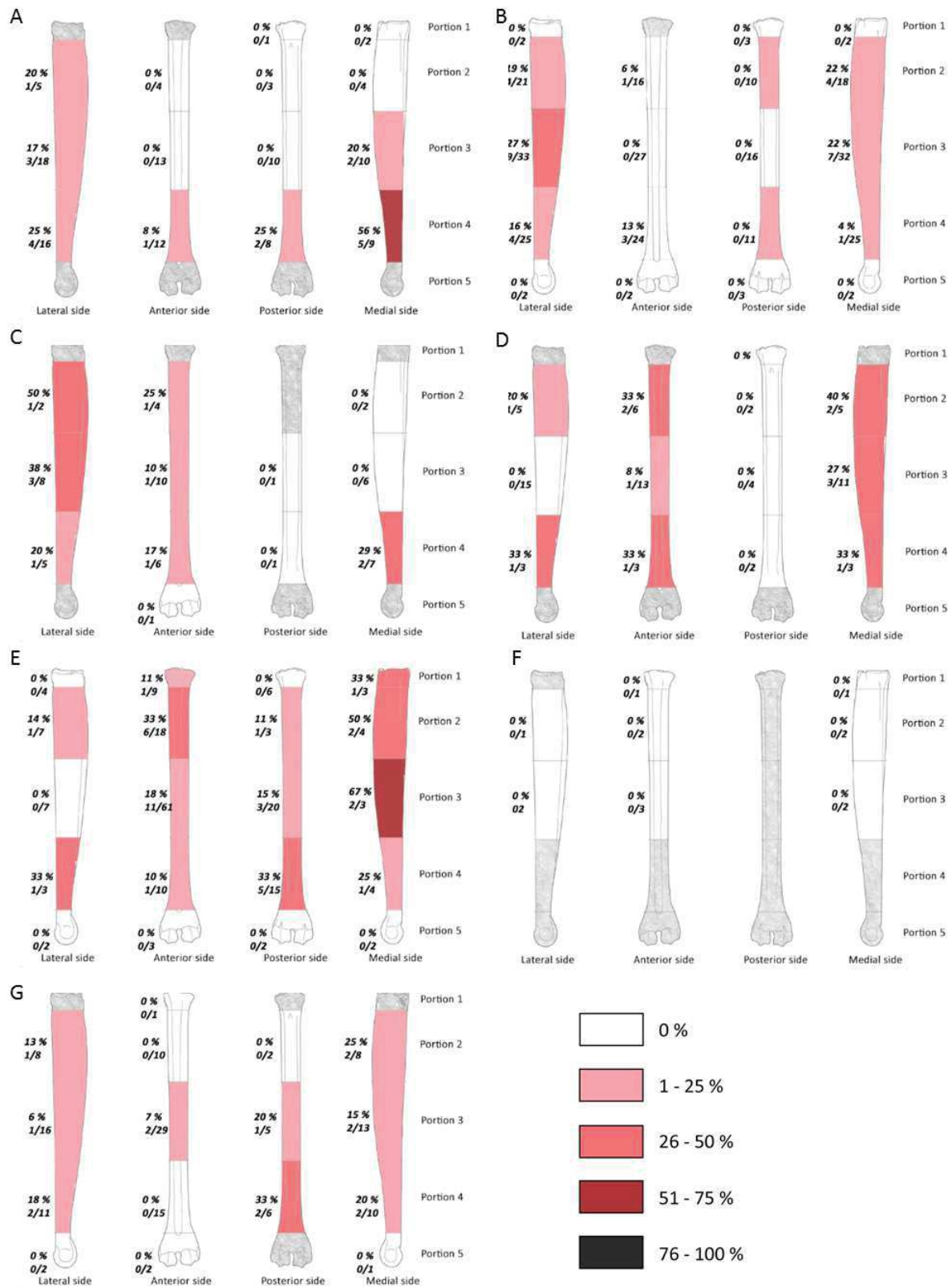


Figure 9: Frequencies of number of percussion marks by portion on metatarsal of each sample (% and Number of area with percussion mark(s) / Number of area preserved); Saint Marcel cave level g (A), level h (B); Riparo Tagliente level 35 (C), level 37 (D); Abri du Maras level 4.1 (E), level 4.2 LUNG (F), level 4.2 MUNG. The absence of portion in each assemblage is grey.

Non-random and counter-intuitive distribution of percussion marks

We compare our results with those from [23] from two Middle Palaeolithic Spanish sites (MIS 5-9): Bolomor (levels IV, IX, XIIa and XIIc) and Gran Dolina (TD10-1).) from two Middle Palaeolithic Spanish sites (MIS 5-9): Bolomor (levels IV, IX, XIIa and XIIc) and Gran Dolina (TD10-1). For the experimental data, we used the intuitive pattern presented in Vettese et al. (in prep.) (Figure 10, 11 and 12).

The hypothesis tested on the archaeological samples, including comparative data, is the presence of a random pattern of percussion mark distribution. When data are quantitatively limited, we group the series from the same site together. The results show that at Bolomor, percussion mark areas are not randomly distributed, in contrast to Gran Dolina with the previously published chi-square. Regarding our studied sites, Riparo Tagliente presents a probable random distribution of the marked areas (Chi-square: p-value > 0.05). Nonetheless, in the site of Abri du Maras, four long bones (Chi-square: humerus: p-value < 0.001, $\chi^2 = 40.86$; radio-ulna: p-value = 0.002, $\chi^2 = 29.53$; femur: p-value < 0.001, $\chi^2 = 21.11$ and metatarsal: p-value = 0.001, $\chi^2 = 31.08$) show that bone areas are not equally impacted. At Saint-Marcel Cave, three long bones (Chi-square: tibia: p-value = 0.031, $\chi^2 = 21.16$; metacarpal: p-value = 0.019, $\chi^2 = 22.76$ and metatarsal: p-value < 0.001, $\chi^2 = 40.06$) yield similar test results.

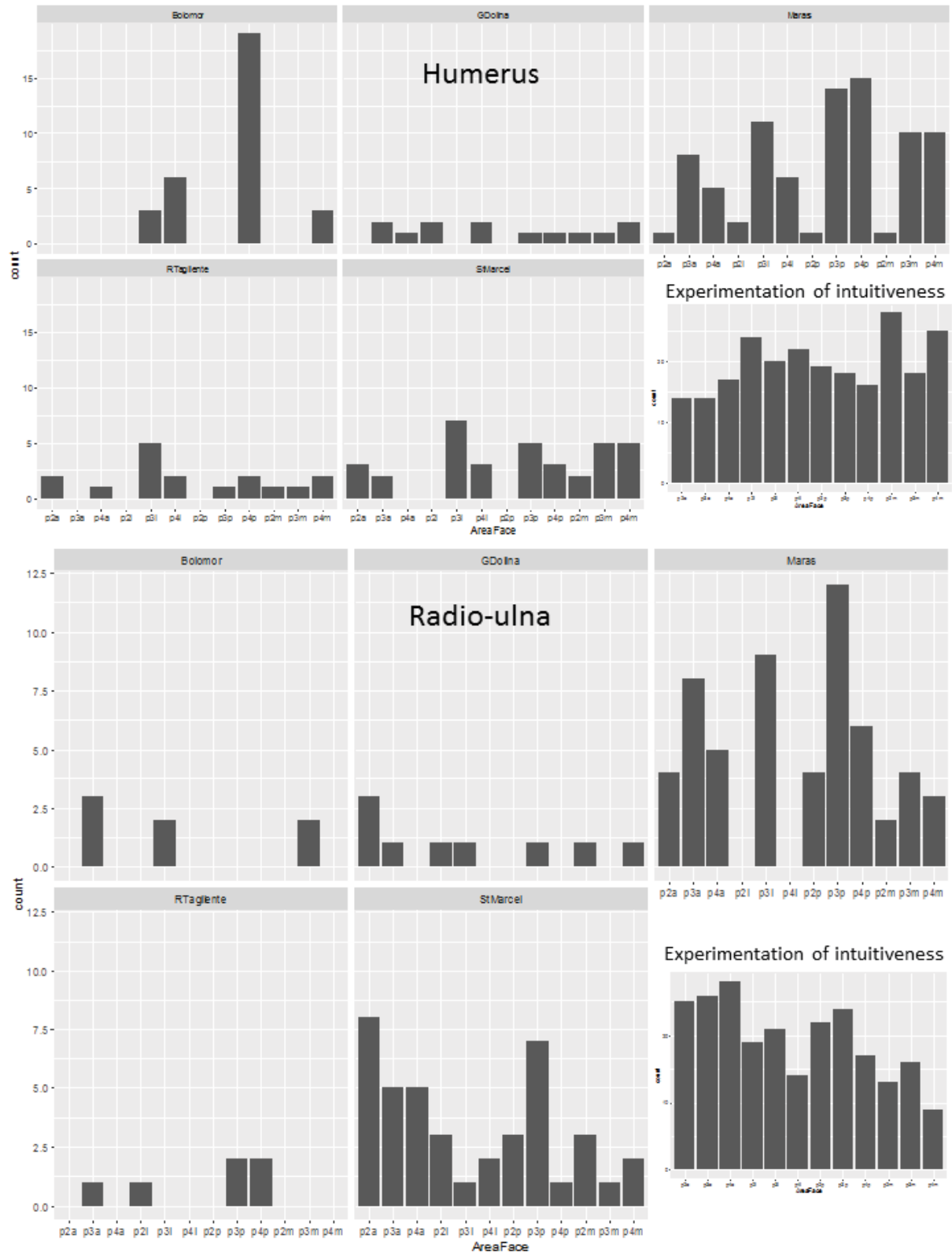


Figure 10: Number of areas with percussion marks for each archaeological site and for the intuitive experiment model for humerus and radio-ulnas.

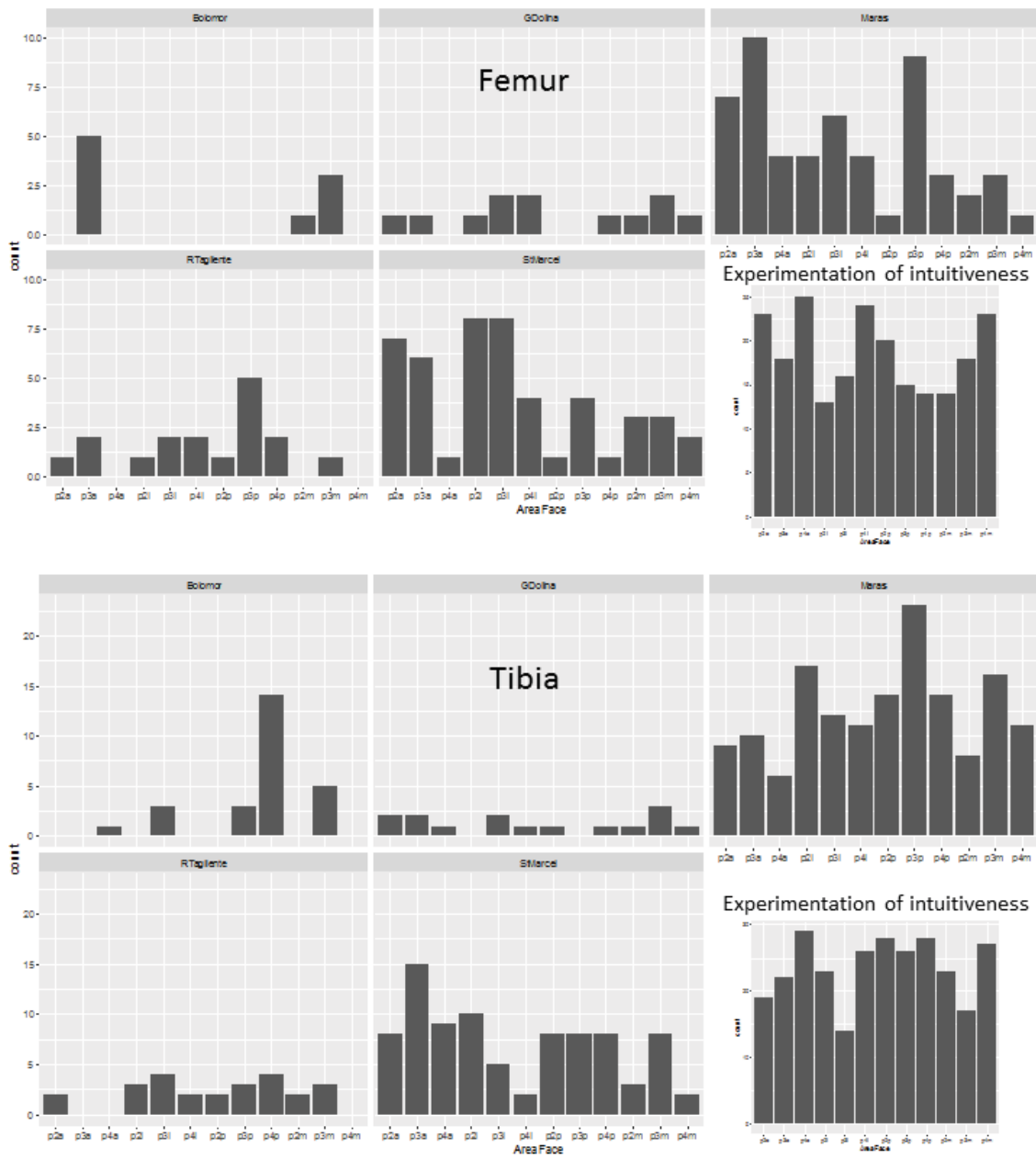


Figure 11: Number of areas with percussion marks for each archaeological site and for the intuitive experiment model for femurs and tibias.

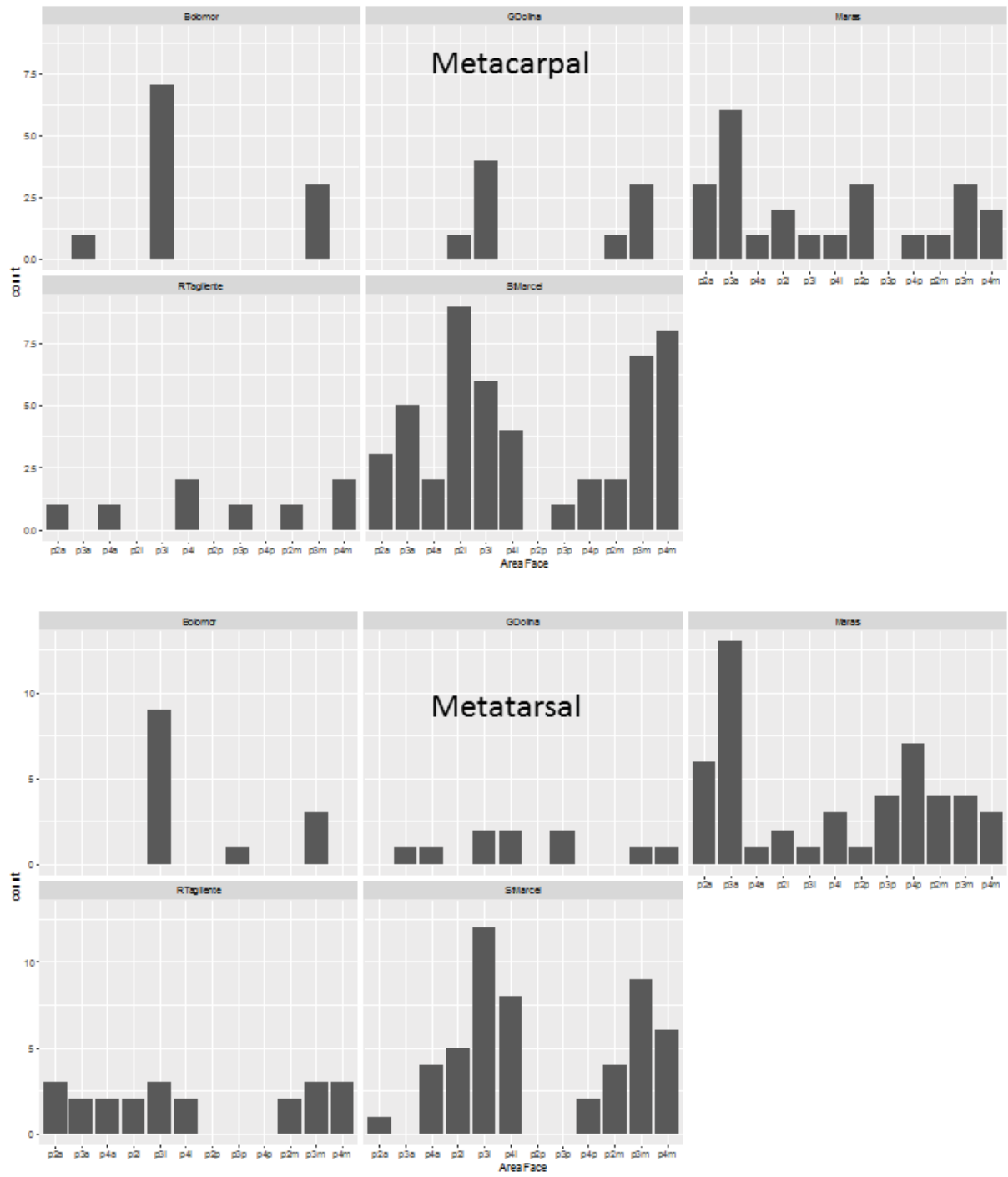


Figure 12: Number of areas with percussion marks for each archaeological site and for the intuitive experiment model for metacarpals and metatarsals.

In order to develop the analysis at an intra-site scale, we need to test each assemblage independently. For the sake of representativeness, we only considered series with at least 15 areas with percussion marks (Figure 10-12). Except the radio-ulna and the metatarsal of Abri du Maras 4.2LUNG, all the elements from the Abri du Maras and Saint-Marcel Cave levels were eligible to be tested. The three Abri du Maras assemblages show differences. The level 4.1 sample presents a non-random distribution of the impacted areas for the humerus (Chi-square: p-value < 0.001, $\chi^2 = 29.11$), the femur (Chi-square: p-value = 0.002, $\chi^2 = 32$) and the metatarsal (Chi-square: p-value < 0.001, $\chi^2 = 38$). In level 4.2, the radio-ulnas of the 4.2MUNG assemblage (Chi-square: p-value = 0.001, $\chi^2 = 30.74$) and the humeri of the 4.2LUNG sample (Chi-square: p-value = 0.003, $\chi^2 = 21.2$) present proportions of bone areas unequally marked by percussion. The Saint-Marcel Cave series shows differences depending on the element. The metatarsal for both series presents a non-random distribution (Chi-square: level g: p-value = 0.02, $\chi^2 = 22$ and level h: p-value < 0.001, $\chi^2 = 35.73$). In layer g, percussion marks are randomly distributed on the metacarpal (Chi-square: p-value = 0.01, $\chi^2 = 24.64$), whereas this is not the case in level h. Finally, bone areas are equally marked for the tibias from each level.

If we only consider the series with non-random distribution, it is possible to discuss butchery traditions or intuitive patterns. Some works highlight the existence of intuitive patterns in percussion mark distribution for marrow recovery, based on experiments involving non-trained experimenters [38]; Vettese et al., in prep.. Using the results of this experiment and chi-square analysis, we compared whether the non-random distribution of percussion marks is statistically different or not from intuitive pattern distribution.

The Bolomor site reveals a different distribution from the intuitive one (Chi-square: p-value < 0.01, humerus: $\chi^2 = 158.58$; femur: $\chi^2 = 39.52$; tibia: $\chi^2 = 39.57$), except for the radio-ulna (Chi-square: p-value > 0.05, $\chi^2 = 19.3$). For radio-ulnas, the same results were noted as for radio-ulnas in Vettese et al. (in prep.). In the Abri du Maras and Saint-Marcel Cave series, only the elements with non-random percussion mark distribution were tested with intuitive patterns. All of them show a different distribution to the intuitive pattern (Chi-square: Maras: humerus, p-value < 0.001, $\chi^2 = 51.86$; radius, p-value = 0.033, $\chi^2 = 21.01$ and femur, p-value = 0.006, $\chi^2 = 26.1$; Saint-Marcel: tibia, p-value = 0.008, $\chi^2 = 25.53$). Moreover, at Abri du Maras, the elements with results showing unequal marked areas also display a different distribution from an intuitive pattern (Chi-square: Maras, 4.1: humerus, p-value < 0.001, $\chi^2 = 38.43$ and femur, p-value < 0.001, $\chi^2 = 38.82$; 4.2MUNG: radius, p-value < 0.001, $\chi^2 = 22.69$ and 4.2LUNG: humerus, p-value = 0.002, $\chi^2 = 21.96$).

Significate differences between assemblages

On the Figure, the MCA includes both the bone areas with and without percussion marks (Supplementary data 6). The first axis, accounting for around 17% of the total variance, is related to the variable which is impacted or not, with impacted areas on the right of the chart and non-impacted areas on the left. Predictably, the experiment yielded more preserved and impacted areas than the archaeological assemblages. Also, the most impacted portion and side seem to be respectively portion 3 and the medial side. In the controlled experiment, all the remains were kept and conserved, whereas several remains are missing from the archaeological series due to differential conservation or problems of identification (Supplementary data 7) (Figure 10, 11 and 12).

In order to examine in more detail the relation between the portions and the sides bearing percussion marks depending on the sites and bone elements, we excluded areas without percussion marks from the analysis. The location of percussion marks on the portions and sides are used to build the axes of the MCA while the sites and their levels are displayed as illustrative variables. Separate MCA are computed for each bone element (Figure 13, 14 and 15). In most of the plots, most of the sites are very close to the centre of the graph, showing that it is difficult to differentiate the sites and the experiments based on these variables. For the humerus plot, the Abri du Maras seems to be different to the intuitive experiment, but the series are close to the other sites. On the radio-ulna graph, the Abri du Maras and Saint-Marcel series show some differences, but they are encompassed in the ellipse of Gran Dolina and Riparo Tagliente. Regarding the femur, the ellipses of the Saint-Marcel, Abri du Maras and Riparo Tagliente assemblages intersect but they present differences. Nevertheless, the series of Saint-Marcel and Abri du Maras are included in the ellipse of Gran Dolina. However, the site of Bolomor is always far removed from the other experimental and archaeological groups.

Regarding the MCA including experimental data, we observe that the batting experiment is distant from the other experiments [23,105]. The more impacted areas are on radio-ulna, the portion 2 and posterior side, on femur the portion 2 and anterior side and on tibia with the more impacted area the portion 2 and lateral side (lateral side has a low \cos^2) (Figure 13 and 14). The other experiment of [23] is quite distant from the centre (humerus, radio-ulna and femur), but less than the batting series. The other experimental assemblages are grouped towards the plot centre, showing that the considered variables (the portion or the side) are not discriminatory. Besides, the sample from Riparo Tagliente level 35 is distant from the other archaeological assemblages for the femur and humerus.

Regarding the metapodials, the absence of experiments seems to influence plot distribution (Figure 15). For the metapodial graphs, Bolomor shows a certain proximity to the Gran Dolina assemblage with more impact traces on portion 3 and the anterior side (but the anterior side has a low \cos^2) on the metacarpal and on portion 3 and the lateral side on the metatarsal. Bolomor is set apart from our series.

In order to test if the tendencies observed in the MCA are statistically significant (in other words, if they could be due to chance or not), we used the Fisher exact test. The results display significant differences for the area with impact distribution on the metatarsal between Abri du Maras and Saint-Marcel ($p_{3a/p3l}$, p -value < 0.001 and $p_{3a/p4l}$, p -value < 0.001).

Discussion

Through the analysis of seven faunal assemblages from three South European Middle Palaeolithic sites; Abri du Maras, Saint Marcel and Riparo Tagliente, we conducted a large comparative analysis of percussion mark distribution on long bones. In all these series, we observed distinct and homogeneous long bone fragmentation. We also identified a high number of green bone fractures and numerous percussion marks of different types (notches, adhering flakes, pits and grooves) as the result of anthropogenic breakage. The sites record intensive human occupation and the number and diversity of the percussion marks attest to systematic long bone breakage for marrow recovery.

Percussion marks are never systematically located on the same specific bone area in the different layers and sites. However, some tendencies emerge and the heterogeneous percussion mark distribution highlights some more marked areas than others. These trends differ according to the elements and faunal series. Our results show that the humeri and the femurs of layer 4.1 of Abri du Maras present a non-random percussion mark distribution, which is different from that obtained in an intuitive context. Likewise, the analyses demonstrate a similarly non-random and counter-intuitive pattern for the percussion mark distribution of the series 4.2LUNG (large-sized ungulate series) humeri and the 4.2 MUNG (middle-sized ungulate series) tibias of Abri du Maras, and also of the Saint-Marcel Cave radio-ulnas. Thus, this particular distribution of percussion marks shows the probable existence of butchery traditions at Abri du Maras layers 4.1, 4.2, Saint-Marcel layers g, and h. At Riparo Tagliente, this is not obvious, due perhaps to statistical biases. However, it was not possible to discriminate sites on the basis of percussion mark distribution, except for the metatarsals from Saint-Marcel and Abri du Maras, indicating a statistically significant difference between them.

Taphonomic biases in the identification of percussion marks

In order to better analyse the distribution of percussion marks, it is necessary to estimate the impact of the different taphonomic factors on faunal assemblages.

Taphonomic differences clearly exist between our sites. The percussion mark ratios from both layers at Abri du Maras are lower than at Riparo Tagliente and Saint Marcel. This is partly due to the greater illegibility of the Abri du Maras bone surfaces (root etching dissolution and desquamation). Indeed, the greatest difference between the series is related to the ratio of pits. While the pits are the second most frequent traces at Saint Marcel and Riparo Tagliente, at Abri du Maras, they are scarce or absent. Pits only alter the superficial cortical surface, whereas notches and adhering flakes penetrate the whole thickness and reach the medullary cavity [106]. Thus, the degree of bone surface preservation may partly explain the limited number of pits in this case. Concretions may also sometimes partially or completely cover the surfaces. The same is true for abrasion alterations, such as polishing. However, oxide coloration, as well as fire surface alterations, do not seem to affect percussion marks.

The degree of post-depositional bone fragmentation should also be considered in percussion mark analysis. In our series, breakage was mainly peri-mortem, as evidenced by the high proportion of green bone fractures. However, some dry bone fractures were also observed, sometimes related to green bone fractures. Post-depositional cracking, dry bone fractures, thermoclasty and gelifraction can duplicate some percussion marks, or affect adhering flakes.

Concerning the impact of differential preservation on percussion mark distribution, we can correlate the absence of crushing marks in our series with the lack of epiphyses. Whether this results from natural or anthropogenic differential preservation (bone fat recovery or fuel), in all cases shaft fragments are much more numerous than epiphyses. Yet, this type of mark is usually located close to the spongy portions (Vettese et al. in prep).

To conclude, despite all these taphonomic biases, the percussion mark ratios (Number of remains with percussion marks / NISPa) recorded in our assemblages are still higher than in other sites, such as Fumane [107], Saint-Germain-la-Rivière [24] or Abric Romani [108]. This indicates systematic marrow extraction by percussion at these three sites.

Percussion marks: a valuable indicator of butchery traditions?

None of our assemblages shows a systematic location of the percussion marks (Figure 4-12). Thus, our results seem to be more similar to those observed at Gran Dolina TD10-1 [23].

Percussion mark frequencies indicate some tendencies, but their location varies according to the elements or the series, for example, the humerus (p31) at Saint-Marcel (layer g) and Abri du Maras (series 4.2LUNG) (Figure 4). No correlation was observed between distribution and bone density or cortical thickness. However, percussion mark tendencies were not sufficient to evoke the presence of standardization. Areas with percussion marks also show tendencies rather than systematization. Before attempting to interpret them in terms of traditions, we would like to assess whether these observed tendencies are randomly caused, and if we can rule out the standardization of percussion mark distribution.

In our studied samples, we observe two cases: the first with random distribution of percussion marks, and the second with standardized distribution.

In the first case, such as at Riparo Tagliente, we can suggest that several groups or individuals extracted marrow differently during recurrent occupations –palimpsest [43,51,109,110]. Due to the limited number of remains at Riparo Tagliente, for example, both layers were analysed together, erasing possible differences. The high fragmentation of the bones to extract yellow and red marrow, in order to use the spongiosa as fuel or to make tools, such as retouchers, could also erase the systematic percussion areas produced during yellow marrow extraction. Indeed, these activities could produce more percussion marks in different locations depending on the use of the bone fragment.

In the second case, when the proportions of marked bone areas are not randomly distributed, such as at Abri du Maras or Saint-Marcel (tibiae only), this could be due to a yellow marrow extraction tradition or an intuitive way to break bones.

In attempt to recognize the factor, we tested whether the identified standardization is similar to the intuitive pattern or not, in order to interpret the standardization as culturally induced. Some features of percussion mark distribution at Abri du Maras are non-random and are very different to the intuitive pattern (layer 4.1, humerus and femur; layer 4.2 of humerus of the LUNG series and radio-ulna of the MUNG series). This seems to imply probable butchery traditions for some elements. Nevertheless, in layer 4.2, this non-random feature only concerns one bone, i.e., the LUNG (humerus) and the MUNG (radio-ulna) series. This difference could be explained by a dissimilar treatment of the two different-sized ungulates in the two layers. Data from the Abri du Maras assemblages demonstrate that one assemblage with non-random and counter-intuitive percussion mark distribution in one level could influence a larger assemblage of one site. In other words, standardization could be highlighted in the occupation palimpsest. The association of two assemblages can be relevant, given the statistically significant results, as observed at Abri du

Maras. However, standardization could only be highlighted by taking into account several layers, as at Saint Marcel.

In the case of the absence of randomization and counter-intuitive patterns, the hypothesis of a butchery tradition can be reasonably assumed when distribution is standardized. Specific and systematic yellow marrow extraction know-how could be partially erased by taphonomy or additional activities after marrow recovery. Furthermore, the marrow extraction process could necessitate breaking the diaphysis several times to recover the highest quantity of marrow [111]. Consequently, it could be possible to identify standardized practices for some long bones, but not for all of them.

This methodological approach, which tests the standardized and counterintuitive distribution with the chi-square test allows us to reveal possible butchery traditions in the assemblage of Abri du Maras layer 4.1, whereas the analysis of percussion mark frequencies failed to do so [16]. Together, the two Saint-Marcel layers demonstrate the existence of a same tradition only for tibias. Thus, groups with similar practices may have occupied the cave.

At Abri du Maras, Neandertal groups with marrow recovery skills may have transmitted standardized practices and gestures. Furthermore, the practices of the group(s) in layer 4.1 seem to have been different from those of the group(s) in layer 4.2. This latter group processed bones differently, depending on the size of the ungulate. The absence of the clear systematization of percussion mark location in the Abri du Maras series could be explained in two ways: a complex “*chaîne opératoire*”, or the occasional passage of groups with different butchery practices, or both.

However, this methodology is limited to the number of preserved areas with percussion marks. In our study, the emblematic example is the layers of Riparo Tagliente. Percussion mark frequencies indicate differences in bone treatment. However, due to the scarcity of remains, the chi-square analyses do not discern differences between layers 35 and 37. Thus, it is not possible to establish whether the lack of differences is due to the combined study of both layers or to the absence of butchery traditions. The methodology thus needs to be refined to resolve such questions.

The distribution of the recorded percussion marks is never systematic at all the sites where percussion mark distribution was studied: in Abri du Maras, Saint-Marcel Cave, Riparo Tagliente, Gran Dolina [23], Fumane [107] and Saint-Germain-la-Rivière [24] with the exception of Bolomor (layer IV). In this specific layer of Bolomor, we observed one or two systematic areas with

percussion marks. This could highlight a very original marrow extraction practice with specific marrow consumption, perhaps heated [111].

Interrelated traditions among technological and subsistence strategies?

The hunting strategies of the three sites are different, as Neandertal groups selected different cervid species according to the sites. However, almost all the samples were practically monospecific, except the 4.2LUNG (Abri du Maras). Technical behaviour varied from one site to another with changes between some layers. The comparison of these differences with possible butchery traditions enables us to conduct an in-depth investigation of the diversity of Neandertal behaviour at the intra or inter-site scale.

At Riparo Tagliente, technical strategies change between layer 35 and 37 with the emergence of laminar core technology, whereas hunting strategies remained similar. The Neandertal groups occupying those layers chose to hunt only roe deer, focusing on the ecological specialization of medium to large ungulates. It was not possible to identify specific standardized marrow recovery [11,112,113].

At the inter-site scale, the sites of Abri du Maras and Saint-Marcel are relatively close both geographically and chronologically (Figure 1). It is possible to propose the presence of the same groups with similar butchery traditions. However, the main core technology is Levallois/other technologies for Abri du Maras and discoid for Saint Marcel. Neandertal groups were highly mobile, and each assemblage can be due to complex occupation events depending on the season, animal migration or raw material requirements [114,115]. Furthermore, each layer was an occupation palimpsest showing several successive occupations by one or several groups. Hunting strategies are characterized by an almost mono-specific spectrum of middle-sized ungulates for layer 4.1 of Abri du Maras and both layers of Saint-Marcel Cave. The site was occupied at a particular period of the year: autumn for Abri du Maras layer 4.1 and the spring-summer period for Saint-Marcel Cave and for layer 4.2 of Abri du Maras. However, yellow marrow is extracted differently at those two sites, in particular for metapodials. Thus, these results show that the two sites were occupied by different groups with no marrow recovery traditions at a regional scale, between Abri du Maras and Saint-Marcel Cave. Moreover, technical strategies were quite different in the two sites (Levallois and discoid), corroborating the hypothesis of groups with different cultural traditions and hunting and butchery strategies [42].

Regarding the intra site-layer comparison, the technical strategies are similar between both layers g and h of Saint-Marcel cave. Moreover, hunting strategies are also similar. The red deers were the most hunted species in the two layers [116]. These common strategies could be reflected by similar butchery practices, as attested by the tibias and probably the metapodials. Nevertheless, this could not be demonstrated at the scale of each layer.

At Abri du Maras layers 4.1 and 4.2, technological behaviours differ slightly from one layer to the other (same diversity of core technologies but more retouched material for layer 4.2), in the same way as hunting strategies. Layer 4.1 is characterized by selective reindeer hunting [51]. We note standardized practices and thus possible specialization in marrow extraction regarding the stylopodials. The hunting and marrow recovery strategies are different in layer 4.2. Reindeer still dominates the faunal spectrum, but the proportions of other large ungulates are higher. We observe distinct marrow extraction methods for the different ungulate class-sizes for each assemblage. The breakage of the humerus is more standardized for large ungulates and the breakage of the radio-ulna is more standardized for middle-sized ungulates. This site illustrates slight changes in butchery traditions over time between two different phases of occupations. The groups occupying layer 4.2 extracted marrow differently depending on the size of the herbivores. Therefore, it was probable that two different groups with their own butchery traditions occupied the site over time.

Only some long bones from Abri du Maras and Saint-Marcel Cave were broken in a standard way. Moreover, the standardly broken bones were different depending on the site or the series. This bone treatment could point to task division or time-delayed consumption [14,117,118]. Based on ethnographic studies, we can propose several hypotheses to explain differential bone treatment. Several works focusing on current hunter-gatherer societies report that some bones were cracked directly on the kill-site for immediate marrow consumption ("snack"), while others were packed and transported to the base camp for delayed consumption; e.g., [14,117–121]. Hunters seemed to prefer zeugopodials and metapodials for snacking and raw consumption. In this case, the bone remains were abandoned on the site. The femurs and humeri were transported to the base camp to be shared by the group. They were cooked and later broken to be eaten. Binford [119] observed task distribution for femurs, which were broken by women at the camp base. Some groups, such as the Hazda, process carcasses differently, depending on the size of the hunted animals [120].

We could not apply this observation directly to our Neandertal group assemblages. However, the hypothesis of differential long bone treatment depending on the type of occupation

could be backed up by the results from layer 4.1 of Abri du Maras. Only the stylopodials were traditionally broken to recover marrow, which could then have been cooked (see references above). The different treatment depending on species size observed in layer 4.2 between the 4.2MUNG and the 4.2LUNG was also observed in the Hazda, for example [120].

Our data attest to variability in Neandertal behaviour during the Middle Palaeolithic, and not only for subsistence patterns. This variability can be partly explained by the geographical extension and duration of this period associated with the diversity of environmental conditions. Each context seems to represent a balanced response to specific conditions. Based on this assumption, the existence of different butchery traditions is highly plausible. Variability in traditions could be noticed in subsistence, including both hunting and butchery strategies, and technical strategies, as observed in the sites and layers of Abri du Maras, Saint-Marcel Cave and Riparo Tagliente.

Conclusion

Our results suggest the probable presence of butchery traditions in the Maras and Saint Marcel sites, particularly at Abri du Maras, where the level 4.1 series presents standardized and counter-intuitive distributions on humeri and femurs. The samples from level 4.2 show that tibias from medium-sized ungulates were processed traditionally (mainly reindeer), whereas for large ungulates, this was only the case for the humerus. This suggests a difference in marrow recovery processes related to animal size.

For Saint-Marcel, the distribution of percussion marks on radio-ulnas shows standardized marrow extraction practices for the site (both series), but this standardization disappears when the levels are tested separately. This difference points to a relatively minor trend in both levels, which may not be distinguishable for a single level.

The distribution of percussion marks on the metapods of the Maras and Saint-Marcel rock shelters is not random. However, no comparative experimental sample is available for these elements, so it is not possible to determine if the marrow was extracted intuitively or counter-intuitively.

The groups that occupied these French sites processed some long bones in a standard way. However, these elements are different depending on the series. This first analysis does not yield any information on the specificity of the characteristic patterns of these sites or levels.

It was not possible to put forward hypotheses regarding Riparo Tagliente, in particular because of the limited number of bones studied.

Through the comparison of all the sites, as well as intuitive experiments, based on the analyses of percussion mark distribution using exploratory analysis (MCA), we showed that for each element the Bolomor site almost always differs from the other sites and experiments. Those assemblages seem to be different from the other sites, showing particular areas marked by percussion, different from the other samples.

The additional analysis of the Fisher Exact test did not reveal a site-specific percussion pattern based on a particular percussion zone. Nevertheless, we identified one exception: the Saint-Marcel and Abri du Maras metatarsals, where the analysis revealed significant differences in the number of traces observed between the p3a (Saint-Marcel) and p3l/p4l (Abri du Maras) areas. For metatarsals, in these two sites, despite the absence of comparative experimental data, we can suggest the presence of traditional marrow extraction. In addition, for this element only, the traditions appear to be different from each other. For other sites and elements, it is not possible to discriminate between one site and another, solely on the basis of the specific distribution of percussion marks.

These results suggest that despite relatively poor surface conservation, percussion marks are robust enough to demonstrate the existence of butchery traditions in anthropogenic accumulations during the Middle Palaeolithic.

In this paper, we established how several taphonomic modifications could affect percussion traces in an archaeological context in Abri du Maras, Saint-Marcel and Riparo Tagliente. We suggest taking into consideration the degree of surface illegibility in percussion mark counts, especially for pits and grooves. Furthermore, differential preservation influences some traces, in particular, crushing marks.

Such work based on the distribution of percussion marks is certainly time-consuming, but it enables us to further the debate on the socio-cultural practices of Neandertal groups. We need to pursue this research and increase the corpus of sites to enhance our understanding of the different standardized and counter-intuitive practices for the Middle and Upper Palaeolithic in order to discern differences between Neandertal and modern human groups.

In the future, a new methodological approach based on spatial analysis to study percussion mark distribution should be tested [38]. This method takes into account the spatial relation of percussion traces and the preservation of long bone remains, and facilitates analyses

of the marks without the arbitrary division of long bones. Moreover, this method, using GIS analyses, has provided results for intuitive experiments. The comparison between the intuitive pattern and the archaeological series could fine-tune our comprehension of Neandertal and modern human butchery behaviours. It may also be necessary to carry out complementary experiments based on intuitive ways of recovering yellow marrow, in particular, on metapodials.

This study brings new data relating to the social structure of Neandertal groups. The group composition of le Rozel with a majority of children and adolescents bring new evidence to interrogate the relation between the group members [123]. This group is composed of a relatively reduced number of individuals, who repeatedly occupied a site and a layer, with different subsistence or technical strategies. The study of this site will put our results into perspective and further our understanding of socio-cultural dynamics? We can now consider the practice of bone marrow recovery as one of the structuring elements of a more global reflection on interactions and intergenerational transmission.

These butchery traditions highlighted complex practices within human groups and practices that may diverged between layers of a site or show a certain continuity of butchering know-how. Our results interrogate if the traditions of lithic, hunting and butchery could be intertwined?

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IV. 4. Conclusion

Les deux travaux complémentaires réalisés en début et en fin de thèse (Vettese et al., 2017, **Publication n°4**; en préparation, **Publication n°5**) montrent toute la complexité d'utiliser la distribution des marques de percussion comme outil pour mettre en évidence des traditions bouchères en contexte archéologique.

Le premier article a permis de poser la réflexion qui fut à l'origine de ce projet doctoral et les jalons méthodologiques permettant sa mise en œuvre. Les résultats de cette première étude menée sur le niveau 4.1 de l'Abri du Maras n'ont pas permis la mise en évidence de standardisation des pratiques d'extraction de la moelle des os longs. Dans ce niveau, Daujeard et al. (2017) (Annexes, **Publication n°6**) ont mis en évidence des pratiques de chasses au renne quasi-mono spécifiques. Cette étude indique que le ou les groupes néandertaliens ayant occupé l'abri ont organisé des épisodes de chasse collective de masse de troupeaux de rennes en automne. L'analyse archéozoologique montre le transport sélectif de certaines parties de carcasses vers le site, en particulier pour les os longs, les éléments contenant le plus de moelle jaune (Vettese et al., 2017). Ce niveau 4.1, représentant un palimpseste d'occupations serait-il alors possible d'avoir plusieurs groupes ou un seul groupe qui seraient revenus, mais avec des individus chassant ensemble mais ne partageant pas les mêmes traditions bouchères ?

Dans le second article (**Publication n°5**), nous nous avons tenté d'évaluer l'impact des diverses altérations taphonomiques sur les marques de percussion. Selon nos observations, les marques de percussion de surface (*pits* ou les *grooves*) sont les plus impactées. Nous suggérons de prendre en compte l'intensité des modifications taphonomiques dans le décompte de ces marques. En outre, la rareté des épiphyses (conservation différentielle anthropique ou naturelle) expliquerait l'absence de marques d'écrasement dans nos assemblages. Cependant, nous avons pu mettre en lumière que seule une modification profonde de l'os ou sa disparition empêchent l'enregistrement des encoches qui sont un bon marqueur de percussion.

Une fois les biais taphonomiques écartés, d'une part et malgré l'absence claire d'une systématisation, d'autre part, il a été possible d'identifier des tendances dans la localisation des marques de percussion sur certains éléments osseux. La présence d'une distribution non-aléatoire donc standardisée des traces et leur contraste avec les schémas intuitifs a permis dans certains cas d'aller dans le sens de l'existence de traditions bouchères au sein d'un ou plusieurs niveaux d'un site archéologique.

Ainsi, sur le site de Saint-Marcel, des groupes différents de néandertaliens se sont succédés durant le remplissage des deux niveaux, mais il semblerait que certains partageaient des pratiques similaires de récupération de la moelle, notamment pour les tibias. En outre, le niveau 4.1 et le niveau 4.2 de l'Abri du Maras présentent des pratiques bouchères similaires au sein d'un même niveau pour des os longs comme l'humérus ou le fémur. Ce site est d'autant plus intéressant, que les groupes présents dans les deux niveaux semblent avoir adopté des traditions sur des éléments différents et que le niveau 4.2 montre un traitement distinct selon la taille des espèces.

Par ailleurs, il a été possible de mettre en évidence des savoir-faire significativement différents dans le traitement des métatarses à l'Abri du Maras et à la grotte de Saint-Marcel. Cependant, l'absence de séries expérimentales de comparaison pour cet élément ne nous a pas permis de démontrer la présence de pratiques contre-intuitive d'extraction de la moelle.

Enfin, les séries provenant des deux niveaux de Riparo Tagliente montrent des distributions semblant indiquer une possible standardisation. Cependant, au vue du trop faible nombre de restes mis au jour dans ces niveaux pris indépendamment, il n'a pas été possible de mettre statistiquement en évidence des pratiques traditionnelles de récupération de la moelle jaune. Cela montre les limites de cette approche qui nécessite un grand nombre d'ossements portant des marques de percussion localisée.

Ces résultats montrent à la fois tout le potentiel de telles études s'intéressant aux pratiques traditionnelles bouchères, mais soulignent aussi leurs biais et leurs limites. De plus, l'intrication complexe de la chaîne opératoire de boucherie (combustible, graisse osseuse ou industrie osseuse) pourrait effacer en partie une pratique de récupération de la moelle jaune standardisée, tout comme, les altérations taphonomiques de surface post-dépositionnelles.

Comme perspectives, il serait intéressant de tester la méthodologie d'analyse spatiale (SIG) sur des assemblages fauniques fossiles mise en place pour le matériel expérimental (Chapitre III). En effet, l'enregistrement des restes et des marques de percussion grâce au logiciel SIG pourrait permettre une plus grande précision dans l'étude des données spatiales. En outre, l'analyse par Points Chauds Optimisés pourraient apporter des résultats complémentaires à ce type d'étude. Il serait possible de mettre en évidence des zones de concentration que nous pourrions aisément comparer à celles mises en exergue lors de l'analyse des restes issus de notre expérimentation sur l'intuitivité.

Le remontage systématique de tous les restes fauniques au sein des assemblages pourrait aussi permettre d'augmenter le nombre de marques de percussion localisées. En effet, des fragments non identifiés pourraient s'avérer déterminable après les remontages et ainsi il serait possible de localiser des marques de percussion supplémentaires.

Cette approche pourrait être aussi utilisée pour les mandibules ou les phalanges dans les sites où elles ont également fait l'objet d'une intense fracturation pour extraire la moelle. En outre, ces éléments sont plus facilement identifiables anatomiquement que les diaphyses des os longs.

*Approche techno-culturelle de la fracturation des os longs chez les Néandertaliens (Sud-Ouest de l'Europe, MIS 5-3) :
une systématisation des gestes ?*

Chapitre V.

Conclusions et perspectives

*Approche techno-culturelle de la fracturation des os longs chez les Néandertaliens (Sud-Ouest de l'Europe, MIS 5-3) :
une systématisation des gestes ?*

V. 1. Synthèse générale

La compréhension des comportements des groupes néandertaliens requiert une approche pluridisciplinaire ; approche issue de l'analyse combinée des assemblages lithiques et fauniques et des études géochronologiques, paléo-environnementales ou encore géotopographiques. Ce travail de recherche concerne les comportements de subsistance, et plus particulièrement la question de l'existence de traditions bouchères au Paléolithique moyen (MIS 3-4). Cette interrogation est basée sur les marques de percussion dues à l'extraction de la moelle osseuse. Cet objectif s'inscrit dans une démarche actualiste croisant les données archéozoologiques et expérimentales. La mise en perspective de nos résultats avec les autres données matérielles, telles que les traditions techniques culturelles ou encore les stratégies liées au type de chasse et à la boucherie, est également un point important de notre étude.

Sur la base de l'étude archéozoologique d'assemblages fauniques et plus spécifiquement de la distribution des marques de percussion dans plusieurs sites néandertaliens récents (MIS 4 et 3) du Sud-Est de la France (Abri du Maras et grotte de Saint-Marcel) et du Nord de l'Italie (Riparo Tagliente), nous avons testé l'hypothèse de l'existence de traditions bouchères distinctes à l'échelle d'un site. Postulat que nous avons examiné à une échelle régionale, en intégrant des sites de comparaison de la péninsule ibérique : Bolomor (MIS 5) et Gran Dolina (MIS 9) (Blasco et al., 2013). Ce travail a été l'un des premiers à traiter à grande échelle la question de l'identification de traditions bouchères distinctes au sein des groupes de Néandertaliens du Sud-Ouest de l'Europe. La question de la présence de pratiques bouchères standardisées implique celle d'une transmission et d'un apprentissage des savoir-faire. Il peut donc apporter des informations sur les comportements de subsistance et le contexte socio-culturel des groupes humains.

Au travers des différents aspects abordés dans cette recherche, nous avons en filigrane répondu à des problématiques méthodologiques. Elle nous a permis d'apporter des outils techniques indispensables pour étudier les marques de percussion et leur distribution spatiale sur les os longs (Stavrova et al., 2019). Au-delà des principaux objectifs de ce travail doctoral, c'est à dire l'identification de traditions bouchères ; les méthodes utilisées pourront être appliquées de façon généralisée et servir à la reconnaissance des marques liées à la fracturation osseuse.

Quelles marques doivent être prises en compte et analysées pour rendre compte précisément des gestes des bouchers néandertaliens ?

La révision de la terminologie des marques de percussion a permis une meilleure identification et caractérisation de ces traces et, nous l'espérons, une clarification pour les travaux futurs qui s'intéresseront aux activités anthropiques de percussion. Nous avons choisi de baser cette terminologie des traces produites lors de la percussion sur une nomenclature descriptive des marques de percussion, afin de ne pas sur-interpréter les traces en contexte archéologique. Nous avons donc proposé de classer les marques selon trois catégories distinctes : 1) les marques de percussion *sensu stricto*, 2) les marques consécutives à la fracturation (l'ouverture de la cavité médullaire) et 3) les stries liées à la percussion. Ainsi, seule la première catégorie, les marques de percussion proprement dites, ont été prises en compte dans tous les travaux expérimentaux et archéologiques menés dans le cadre de cette thèse. En effet, seules ces marques permettent d'identifier précisément la localisation des coups opérés lors de la fracturation osseuse, et de fait, d'obtenir une distribution spatiale des coups au plus près des gestes des Néandertaliens.

Par ailleurs, nous avons aussi pu montrer la double équifinalité des traces de percussion. Effectivement, un même outil peut produire plusieurs types de marques et des outils différents peuvent produire un même type de stigmat. Les illustrations de l'atlas réalisé pour cette étude sont majoritairement issues de l'expérimentation intuitive que nous avons menée. Par analogie, ces illustrations permettent d'identifier les marques observées en contexte archéologique en s'appuyant sur les traces produites lors d'une expérimentation contrôlée (Chapitre III).

Quelles méthodes analytiques permettent d'illustrer, quantifier et analyser spatialement les marques de percussion afin de mettre en évidence des zones de plus grande concentration? Existe-t-il une manière intuitive de fracturer les os longs d'un animal pour en extraire la moelle ? Quelles sont les variables qui pourraient influencer cette approche intuitive ?

Le volet expérimental a permis de tester le rôle de l'intuitivité des gestes dans la pratique d'extraction de la moelle jaune, sur la base de la localisation des marques de percussion. Nous avons réalisé une vaste expérimentation sur la fracturation des os longs d'ongulés en contexte intuitif qui nous a permis de constituer un vaste référentiel expérimental sur les marques de percussion, la fracturation osseuse et les comportements des individus lors de la fracturation. Notre référentiel expérimental a en effet servi d'une part à préciser la morphologie et les caractéristiques spécifiques permettant l'identification de ces traces et d'autre part, à réviser la

terminologie des marques liées à l'extraction de moelle par percussion (Chapitre II, Publication n°1).

Par ailleurs, nous avons mis en place de nouvelles approches méthodologiques pour aborder l'analyse de la distribution des marques de percussion pour l'analyse des traces expérimentales. La mise en place d'un protocole standard d'enregistrement et d'analyse spatiale SIG des marques de percussion expérimentales, a été primordiale dans le développement d'une méthode d'étude innovante de la distribution des marques de percussion (Publication n°2). Cette méthode visuelle permet aussi de mettre en évidence des zones de concentration de ces traces statistiquement significatives. Non seulement, ce travail n'avait jamais été réalisé pour ce type de marques, mais l'analyse statistique novatrice des Points Chauds Optimisés utilisée pour l'expérimentation permet d'analyser les quatre faces des os simultanément et non chaque face de façon indépendante. Nous avons pu montrer la pertinence de cette méthode dans l'étude de la distribution des marques de percussion en contexte expérimental.

Nos résultats ont mis en avant des schémas intuitifs différents pour chacun des éléments testés, en particulier pour les humérus, les radio-ulnas et les tibias dépendant de la morphologie de ces éléments. Quant aux fémurs, les comportements individuels semblent avoir plus d'influence que la forme de l'os sur les schémas de répartitions.

Nous avons comparé les distributions intuitives de marques de percussion, avec les distributions issues de chacun des assemblages fauniques archéologiques. Ainsi, nous avons pu affiner nos interprétations sur l'existence probable de traditions bouchères dans les niveaux des sites sélectionnés pour cette étude.

En parallèle, nous avons mené une seconde expérimentation, en réduisant le nombre de variables : un seul individu expérimenté qui fracturait les os, toujours dans la même position et avec toujours les mêmes outils, seul l'élément osseux variait. Nous avons montré que même lorsqu'un individu met en œuvre des pratiques systématiques lors de la fracturation, le schéma des impacts, lui, ne l'est pas forcément. Il est toutefois possible d'observer des tendances de zones osseuses plus impactées que d'autres. Par ailleurs, nous avons observé que les expérimentateurs ne s'arrêtaient pas à la première fracture de l'os, mais cassaient aussi les fragments osseux. Par conséquent, la systématisation de la localisation des premières traces peut être effacée par les coups supplémentaires donnés pour sur-fracturer l'os. Ces résultats soulignent l'importance de l'identification de ces zones, qui pourraient démontrer l'existence de pratiques et de gestes standardisés partiellement effacés par une activité intense de fracturation.

Pouvons-nous déceler la présence de traditions bouchères dans les sites de l'Abri du Maras, de la grotte de Saint Marcel et de Riparo Tagliente ? Si oui, sont-elles différentes ?

L'analyse taphonomique préalable à l'étude de la distribution des marques de percussion a démontré, que les *pits* et les *grooves* de percussion étaient plus susceptibles d'être effacés par les altérations taphonomiques de surface que les encoches de percussion ou les marques d'écrasement. Ces dernières, proches des épiphyses, sont, quant à elles, plus sujettes à la destruction différentielle des parties spongieuses de l'os.

Par ailleurs, pour nos trois sites, la récupération de la moelle jaune n'est pas la seule activité susceptible de laisser des traces de percussion. En effet, une fois la moelle extraite, les épiphyses peuvent être utilisées comme combustible ou réduites en morceaux de plus ou moins grande taille pour extraire la moelle rouge. Quant aux fragments de diaphyses, ils peuvent avoir été utilisés comme retouchoirs. Cette multiplication des traces de percussion, qui ne sont pas liées à l'ouverture de la cavité médullaire à des fins alimentaires, pourrait effacer, du moins partiellement, une distribution systématique ou standardisée des marques en lien avec l'extraction de la moelle jaune.

Pour mettre en évidence la présence de traditions bouchères au sein d'un assemblage sur la base de zones diaphysaires plus percutées, il faut tout d'abord vérifier que les concentrations des marques de percussion observées ne sont ni aléatoires ni similaires aux modèles intuitifs. Cette approche permet de déceler des traditions de récupération de la moelle à partir de distributions de traces de percussion présentant des tendances plus fortes pour certaines zones et non plus seulement une systématisation de l'emplacement de ces marques.

Alors qu'il ne nous avait pas été possible de mettre en évidence la présence de traditions bouchères à l'Abri du Maras dans les premiers temps de ce projet, nous avons pu démontrer dans un second temps la probable présence de pratiques standardisées et contre intuitives, notamment grâce aux résultats de l'expérimentation sur l'intuitivité.

Pour le travail préliminaire (Publication n°4), nous avons travaillé sur la fréquence du nombre de zones portant des marques de percussion sur les os longs comparées aux zones conservées. Les fréquences permettaient de compenser les biais de conservation différentielle (Castel, 2005 ; Blasco *et al.*, 2013 ; Vettese *et al.*, 2017).

Cependant, il s'est avéré que l'utilisation des fréquences entraîne la perte de certaines informations essentielles. Par exemple, il n'est pas possible de faire la différence entre des restes absents et des restes présents dans l'échantillon mais qui n'ont pas trace de percussion.

Nous proposons donc de comparer directement le nombre de zones préservées et celui des zones portant des marques de percussion. Nos résultats nous ont permis de traiter indépendamment ces dernières ont été utilisées préférentiellement tout en essayant de rester prudent dans l'interprétation de nos données du fait de la préservation différentielle.

Ainsi, les groupes néandertaliens ayant occupé l'Abri du Maras lors du remplissage des niveaux 4.1 et 4.2 (MIS 3), avaient vraisemblablement des pratiques bouchères différentes selon les différents os longs (humérus, fémurs et radio-ulnas). Par ailleurs, en comparant conjointement les deux niveaux, les groupes de Néandertaliens ayant occupé l'Abri du Maras et ceux de la grotte de Saint-Marcel laisse à penser que ces groupes avaient probablement des traditions bouchères différentes pour extraire la moelle des métatarses. A Saint-Marcel, les traditions liées à la récupération de la moelle des tibias sont homogènes et paraissent donc se conserver au cours du temps dans les deux niveaux.

Par contre, l'analyse des assemblages fauniques de Riparo Tagliente n'a pas permis de démontrer la présence d'un groupe avec des traditions bouchères. Deux possibilités peuvent être envisagées : soit la succession de plusieurs groupes dans la cavité avec différentes pratiques d'extractions de moelle ; ou bien la présence d'un seul groupe avec des méthodes de fracturation différente selon les individus entre les deux niveaux (35 et 37). Le nombre de restes trop faible dans les deux niveaux ne permet pas de les analyser séparément et d'établir avec certitude si la distribution des marques est aléatoire et donc de démontrer la présence ou non de tradition bouchères dans ce site.

En dépit des biais taphonomiques et de la multiplication possible des traces de percussion par des activités de boucherie différentes de la récupération de la moelle, ce travail a pu démontrer la présence de traditions bouchères. En outre, dans certains sites, les pratiques semblent se modifier d'un niveau à l'autre, indiquant soit des groupes humains différents, soit des activités nécessitant des pratiques de nature variée. Cette modification des pratiques bouchères se traduit aussi par des changements dans les stratégies cynégétiques et dans les traditions techniques d'outils comme nous avons pu l'observer pour l'Abri du Maras. En revanche à Saint-Marcel, il y a un lien entre la continuité des comportements de subsistance et des techniques dans les niveaux étudiés, avec une persistance possible des traditions liées à la récupération de la moelle. Dans les niveaux étudiés de Riparo Tagliente, les groupes néandertaliens ont conservé des stratégies cynégétiques similaires alors que les comportements techniques se sont modifiés. Mais nous n'avons pu démontrer la présence de pratiques bouchères standardisées communes aux deux niveaux.

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V. 2. Perspectives

L'aboutissement de ce travail doctoral ouvre de nombreuses perspectives. Les différentes facettes explorées pour ce projet permettent d'envisager de nouvelles pistes de recherche et l'utilisation d'approches méthodologiques à des fins différentes.

Les approches méthodologiques mises en place pour ce projet sont variées. L'analyse spatiale SIG pourrait être testée sur un plus vaste échantillon archéologique, à la fois pour mettre en évidence d'éventuelles traditions bouchères, ou pour distinguer le rôle des hommes et des carnivores dans la fracturation. La localisation des marques pourrait être en effet un bon outil pour différencier les accumulateurs humains ou carnivores sur un site archéologique (Alcántara García et al., 2006; Parkinson et al., 2014; 2015). Il serait également possible d'illustrer et d'analyser l'impact de la conservation osseuse différentielle dans des assemblages de faunes fossiles sur l'identification des marques de percussion et en particulier sur leur distribution.

Sur la base du référentiel expérimental et au vu du nombre important d'encoches de percussion produites, il serait possible de mettre en place un protocole d'analyse morphogéométrique de ces encoches comme cela a pu être fait pour les *pits* de percussion (Arriaza et al., 2018). Ainsi, nous pourrions tenter de savoir si les types d'outils peuvent avoir une influence sur la morphologie des traces ou s'il est possible de mettre en évidence des caractéristiques spécifiques qui permettraient de discriminer les encoches de percussion des autres encoches produites par pression par exemple (e.g., carnivores) (e.g., Capaldo and Blumenschine, 1994). Enfin, il serait aussi envisageable d'essayer de discriminer morphologiquement le coup du contre coup causé lors de l'utilisation d'une enclume pour extraire la moelle.

En complément de la révision de la terminologie des marques de percussion et de l'atlas illustré (Chapitre II), la mise en place d'un référentiel expérimental et d'une base de données type pour l'étude des marques de percussion nous semblerait intéressante. Cette base pourrait faciliter l'exploitation des données et permettre d'accéder plus rapidement à l'analyse de la distribution de ces traces, permettant d'augmenter ainsi le corpus de sites étudiés sous cet angle

Nous espérons que la collection expérimentale de référence que nous avons constituée pourra être utilisée à la fois pour de la recherche sur la fracturation et les marques de percussion mais aussi à des fins pédagogiques. Cette collection pourra présenter aux étudiants, les différentes marques de percussion et servir de collection de comparaison pour identifier des marques et des fractures.

Les travaux qui s'intéressent à la distribution des marques de percussion sont en effet encore rares, notamment pour les périodes anciennes du fait de contextes difficiles d'accumulations mixtes (Blasco et al., 2013; Masset et al., 2016; Vettese et al., 2017). Les études diachroniques, notamment pour les périodes du Paléolithique, pourraient apporter des informations sur l'évolution des pratiques bouchères pour les diverses espèces d'*Homo*. Au vu des différences à la fois des stratégies cynégétiques et des traditions lithiques, étendre l'aire géographique des sites étudiés par le prisme de la recherche des traditions bouchères pourraient apporter de nouvelles perspectives sur les comportements des Néandertaliens.

En parallèle de l'augmentation des études archéologiques, celle du corpus expérimental semble également essentielle pour mieux comprendre et interpréter les études qui s'intéressent aux traditions bouchères. Des expérimentations complémentaires sur des ongulés de tailles diverses, petits et moyens notamment, permettraient de mesurer l'ampleur des contraintes de la taille et de la forme des os dans la répartition des marques de percussion. D'autre part, il serait également intéressant et complémentaire de mettre en place des expérimentations avec des individus expérimentés, ayant développé des techniques efficaces propres afin de mesurer l'apport des compétences, du savoir-faire et des pratiques standardisées sur la distribution des marques de percussion.

De plus, au vu de l'équifinalité de la production des traces, il serait nécessaire de mesurer l'influence de la morphologie de la forme des outils (galet retouché ou non) et de l'enclume (ronde ou anguleuse), ainsi que celle des matières premières sur la morphologie des traces de percussion.

Par ailleurs, cette méthode d'identification des traditions bouchères basée sur la distribution des marques de percussion sur les os longs, pourrait être utilisée aussi sur d'autres éléments osseux tels que les mandibules ou les phalanges par exemple. Ces ossements étaient également souvent fracturés pour récupérer la moelle. Il serait donc possible d'analyser les distributions des marques de percussion sur ces os à la fois en contexte archéologiques mais aussi en réalisant une expérimentation afin de comprendre la formation et la distribution des marques sur ces éléments.

En outre, les méthodes utilisées pour mettre en évidence des traditions bouchères à partir de l'étude des marques de percussion pourraient être également testées avec les marques de raclage. En effet, comme nous avons pu le démontrer, ces traces, au même titre que les stigmates de percussion résultent d'une action directe et volontaire sur l'os, contrairement aux autres stries de boucheries qui sont des épiphénomènes (Lyman, 1994; Soulier and Costamagno, 2017). Mais

les analyses spatiales pourraient permettre d'émettre des hypothèses complémentaires sur les pratiques de boucherie à partir de l'étude des stries.

Suite à nos observations du matériel expérimental, nous avons relevé des traces produites par le percuteur ou l'enclume qui ressemblent aux marques de retouchoirs. Il serait donc intéressant de confronter, les *pits* de percussion, à des marques de retouchoir expérimentales et à des marques de retouchoirs archéologiques, comme celles des séries que nous avons étudiées, pour mettre en évidence des critères de distinction et d'identification. Cela permettrait de mettre en évidence des pratiques non standardisées et éventuellement poser la question de la transmission à des individus non expérimentés (enfants) qui tâtonneraient. La mise en place d'un protocole d'étude adapté pourrait aussi favoriser l'utilisation de nouvelles approches techniques telles que l'analyse spatiale ou la microscopie pour discriminer ces deux activités.

Enfin, il est aussi possible de s'interroger sur la relation particulière des individus avec leurs outils, qui pouvaient être adaptés à une activité précise. Quelle importance pouvait avoir la taille, le poids, la forme ou le type de matière première du percuteur ou de l'enclume utilisés pour extraire la moelle ? Les percuteurs utilisés pour récupérer la moelle jaune servaient-ils à d'autres activités telles que la taille d'outils lithiques ?

Nos travaux pourraient apporter des éléments à une réflexion sur la cognition des Néandertaliens. Quels étaient les modalités de transmission de ces pratiques bouchères au sein des groupes ? Est-ce que de relations entre les stratégies cynégétiques, les cultures lithiques, les types d'occupation des sites et les traditions bouchères pourraient être établies ? Comment pouvaient s'organiser les différentes étapes de la chaîne opératoire de boucherie, existait-il une distribution des tâches au sein des groupes ? Les chasseurs traitaient-ils eux même l'entièreté des carcasses ?

Ce travail s'inscrit donc dans une démarche réflexive autour des comportements des Néandertaliens et ce qu'ils impliquent comme connaissance sur la cognition de cette espèce humaine. Nous avons apporté des jalons, qui permettront dans le cadre de réflexions pluridisciplinaires de mieux comprendre les pratiques des Néandertaliens.

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Annexes

Annexes 1

Stavrova, T., Borel, A., Daujeard, C., & Vettese, D. (2019). A GIS based approach to long bone breakage patterns derived from marrow extraction. *PloS one*, 14(5), e0216733.

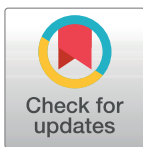
RESEARCH ARTICLE

A GIS based approach to long bone breakage patterns derived from marrow extraction

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Abstract

In archaeological assemblages the presence of percussion marks, on the surface of long bones, is an indicator of long bone marrow extraction. The form, quantity and distribution of percussion marks are analysed to gain a better understanding of the marrow extraction process. Patterns of bone percussion damage in archaeological assemblages may highlight standardized actions, possibly related to butchery traditions. However, additional factors could underlie these patterns and should also be considered. In this article we test intuitiveness as a factor in appearance of percussion mark patterns, to see if patterns can appear when bones are being fractured without prior experience with bone fracture properties. To test this hypothesis, for this study we selected a sample of 40 cattle (*Bos taurus*) long limb bones from a large bone breakage experiment (400 long limb bones), where participants had no previous experience in bone breakage and may thus have broken bones intuitively. We used Geographic Information System (GIS) software to analyse the distribution of percussion marks. Using ArcGIS Spatial Analysts tools, we identified and quantified significant concentrations of percussion marks. Results show that percussion mark patterns emerge for the same bone element, and that specific sides and zones were recurrently selected by experimenters. The distribution of patterns varies among the different long bone elements, and we attribute this variance to an adjustment to bone morphology. In addition, we calculated and identified bone damage patterns resulting from hammerstone percussion. Crossing bone survivorship with percussion mark patterns enabled us to recognise and evaluate the effects of fragmentation and surface visibility in controlled experimental conditions. The GIS method facilitates comparisons between different variables and provides a sophisticated visual representation of results. Enlarging the sample will allow to constitute a more substantial analogous model for fossil assemblages.

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Introduction

Over the past decades, archaeology and human behaviour studies have progressively incorporated research tools and analytical approaches from geospatial sciences. More than 30 years ago, the term GIS (Geographic Information System) was introduced to archaeology [1], and

its application to the field has received mixed reviews over the years. Numerous articles discuss its effectiveness and advantages but also the uncertainty of the system [2–5]. However, since the late 2000s, GIS has rapidly gained momentum and is now an important asset to the archaeologist's tool set.

A GIS is a computer system capable of assembling, storing and manipulating, analysing and displaying geographically referenced information, i.e. data identified according to their location [6]. As stressed by many other definitions [7–9], the key word in GIS is geography and working with this system requires the terrestrial projection of data, meaning a system of coordinates in space that can correspond to latitudes and longitudes. Still, researchers from different fields grasped the potential of the software for non-geographical data and recent studies have used the system in an alternative way to apply the analytical capabilities of GIS to their subjects [10–12]. In a similar manner, we used GIS to illustrate and analyse the distribution of percussion marks produced during bone marrow extraction. The application of GIS to bone was introduced to archaeology by Marean and colleagues [13] to calculate the MNE based on anatomically overlapping specimens. All specimens are digitally drawn in vector mode over templates and then converted into pixels. The maximum number of pixel overlaps detected by the software indicates the MNE. The digitization of the method automated the process of MNE counts and made it appropriate for large assemblages which are otherwise difficult and time consuming to study. This innovative approach received a lot of attention. Lyman [14] argued that MNE calculation with the software could be easily biased by a lack of precision during the drawing of specimens. Others found it valid and continued to develop and adapt the method to more recent versions of GIS [15] and expand its applicability to the analysis of cut marks [16–17].

More recently, Parkinson and colleagues [18–20] proved the software to be well suited to documenting gross bone damage and tooth mark distribution in carnivore-modified assemblages. Spatial point pattern analysis, within GIS, indicates the distribution of tooth marks with greater resolution than previous methods. This allows comparisons with bone portion data. Parkinson's work complements a series of studies that have been developing methodologies for the past three decades to differentiate between human and non-human carnivore modifying agency [21–27]. Her experimental work analysing carnivore marks with GIS provides analogous models for the interpretation of zooarchaeological assemblages and helps to identify the modifier or modifiers and their order of access. In recent years, many archaeological and paleoanthropological research teams have conducted bone breakage experiments subsequent to recurrent comments that bone fracturing and its diagnostic features (pits, notches, adhering flakes and crushing marks) are underexplored. Experiments and consequently developed methodologies broaden the possibilities and provide venues to explore bone breakage processing intensity and butcher investment [28], distinguish grease rendering from marrow extraction [29], and identify cultural patterns in bone breakage processes [30–34]. Recently, Blasco and colleagues [30] have argued that systemized patterns of long bone breakage for recovering marrow can help to identify butchery traditions in Neanderthal groups. To further the subject, of Neanderthal butchery know-how, Vettese [32] conducted a bone breakage experiment (400 long bones) in 2017 with participants that had no previous experience in bone breakage. The main aim of the experiment was to test whether recurrent percussion mark patterns will appear on the bone surface and if so to what extent, when the experimenters have no preconceived concepts on how to perform the task i.e. they will perform the task based on their intuition.

For this study, we selected a sample from this large experimental assemblage to analyse percussion mark patterns with GIS. We adapted and expanded the methods developed for GIS to a recent and updated version of the ArcGIS software (ArcMap 10.4) to explore and

demonstrate some of the analytical possibilities available with this software when applied to percussion marks. More precisely, we set out to:

- Develop an effective GIS protocol to standardize the documentation process (database and visual representation) for fragments and percussion marks deriving from marrow extraction from long limb bones.
- Create an analytical workspace that allows a spatial link between the non-geographic database and its visual representation.
- Explore GIS abilities to record, quantify and illustrate bone fragments and bone survivorship.
- Explore new analytical methods to illustrate, quantify and analyse percussion marks and patterns of percussion marks.
- Test different hypotheses related to intuitive fracturing.
- Choose a model that can provide valuable insights for analogous archaeological assemblages.

Here, we do not examine the issue of how to diagnose or define percussion marks. Rather, our goal is to address the issue of how to record and then analyse them using GIS and ultimately quantify the sample and concentrations of percussion marks for meaningful behavioural analysis, through comparisons with other modern control assemblages or archaeological assemblages.

Material and methods

Material

The studied sample is composed of 40 long limb bones from adult *Bos taurus* species. A series of ten bones was selected from the following elements: humerus, radius-ulna, femur and tibia. Bones were supplied by a slaughterhouse where carcasses were defleshed by a professional butcher. Metapodials are absent from the experiment as they were cut into two parts during the defleshing process, and were thus useless for this experiment.

Non-trained experimenters broke a series of ten long bones to a sufficient extent to remove all marrow (Table 1). Bones were broken with a non-modified quartzite hammerstone (pebble) against a limestone anvil. The periosteum was not removed prior to marrow removal. The experimental bone breakage was performed in a designated area, property of the Muséum National d'Histoire Naturelle, for which all necessary permits were obtained.

After breakage, all the fragments of each element were collected in a single bag associated with an identification code. This code provides information concerning the series and element numbers, which facilitated later identification and refitting. Broken bones were cleaned by the Service of Osteology and Taxidermy Treatment (SPOT) of the National Museum of Natural History of Paris (MNHN). Each bone was treated separately to avoid the loss of small fragments and dissociation from identification codes. Finally, we labelled each fragment with a permanent marker.

Table 1. General information regarding volunteers and bone elements.

Volunteer sex	Volunteer age	Element	Series n°	Number of right elements	Number of left elements
female	29	Humerus	1	3	7
male	40	Radius-ulna	2	6	4
male	25	Femur	3	6	4
male	30	Tibia	4	4	6

<https://doi.org/10.1371/journal.pone.0216733.t001>

Methods

Template/Image preparation and georeferencing. As a base for GIS analysis, we used photographic images representing the four-sided visualization of bone elements [35]. The templates were georeferenced in GIS. As bones are not part of geography, reference coordinates are assigned arbitrarily but they should be specified so that, data can be shared and made compatible with other GIS systems if needed. We used the WGS1984 Greenwich projection. A GIS polygon layer was created over each bone image (Fig 1), replicating the bone silhouette from four views (anterior, lateral, medial and posterior). These templates represent the basis for all further analysis. It is important to note that the area defined by these templates does not reflect the actual bone area. The measurements of all bones from the same element show slight variation and when projected with the software, for the purpose of standardization and superposition of layers, their metric measurements undergo deformations.

Bone refitting and analysis. We examined each specimen and percussion mark individually and in relation to each other through systematic bone refitting for every element. Each fragment was measured (mm) and weighed (g), then labelled with its series number, element number and an individual specimen number (e.g., 1-1-1 = series number-element number-fragment number). Bone refitting generates more precise drawing and localization of fragments and percussion marks in GIS. It also enhances the identification and comprehension of percussion marks, as in some cases, a mark can be obliterated by subsequent blows in the same area, which may be required to fracture the bone completely. When refitting two or more fragments, at times we re-evaluated our judgment based on the analysis of a single fragment, i.e., a single notch can be divided and appear on two (or more) fragments. With refitting we count this as a single percussion mark.

We observed all specimens for surface modifications under a strong light (60 W), first with the naked eye; then with a 15-20X lens. Identification and characterization of percussion modifications are based on descriptions and illustrations of bone surface modifications e.g., [23] [28] [31–32], [36–38].

We recorded the following modifications regrouped in this study under the term percussion marks:

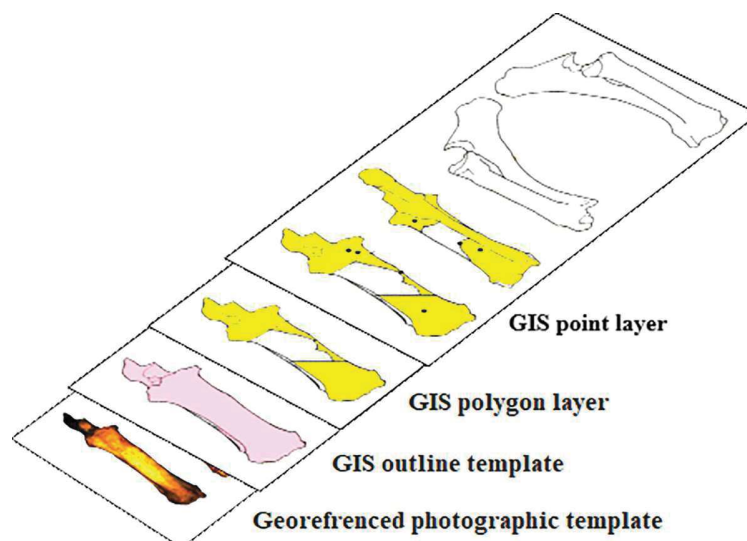


Fig 1. Superposition of GIS layers drawn over the photographic template.

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- Percussion pits,
- Notches,
- Adhering flakes,
- Crushing marks,
- Cortical conchoidal scars.

Pseudo-notches and peeling were not taken into consideration because they are not direct marks but successive results of fractures. We recorded the marks due to blows and counter-blows. We did not observe chop-marks in our sample due to the roundness of the hammerstone pebble and in spite of the anvil's sharp edge.

Drawing fragments in GIS. All identifiable fragments are digitally drawn in GIS, regardless of size. They are drawn in vector mode as polygon features relative to the anatomical landmarks of the previously prepared templates (Fig 1). As defined by previous studies [13], [16], [18–20], identifiable fragments are fragments for which the element and side can be identified and precisely situated on the bone template. We would add to this definition that the outline of the drawn fragment is determined by the outline of the cortical surface of the fragment. This may seem irrelevant, but often fragments that lost part of their cortical surface but conserved medullary surfaces overlap with cortical surface from other fragments from the same bone element, and bias the results. Therefore drawing only the cortical surface circumvents any possible overlapping of fragments of the same bone. Fragments from the same bone element were drawn in a single layer. The radius and ulna were each drawn in a separate layer, in order to eliminate possible errors when calculating bone survivorship or spatial statistics, even though they are fused and generally considered as one element.

An attribute table storing data for every feature, added by the analyst, is linked to every layer. We recorded the reference number for each fragment and the three dimensions (length, width, thickness) were measured for each specimen. Shaft fragments were differentiated by size (Table 2) and circumference classes (Table 3) according to Villa and Mahieu (1991) [38].

Drawing percussion marks. Separate point layers were created to illustrate all the identified percussion marks on the bone surface (Fig 1). We marked them with a point symbol which is also linked to an attribute table with information about the mark:

- n° bone element and n° fragment on which the percussion mark appears,
- Type of percussion mark (notch, pit, adhering flake and crushing),
- Percussion mark maximum length,
- Percussion mark maximum width,
- Percussion mark maximum thickness,
- Notch depth: three different categories: d1 ($< \frac{1}{2}$ initial cortical height), d2 ($> \frac{1}{2}$ and < 1 initial cortical height) and d3 (= 1, total cortical height),

Table 2. Definition of categories separating shaft fragments by size according to Villa and Mahieu (1991) [38].

L1	Shaft fragments that are less than one-fourth the original length of the complete shaft
L2	Shaft fragment length is comprised between one-fourth and one-half of the complete shaft.
L3	Shaft fragment length is between one-half and three-fourths of the complete shaft
L4	Shaft fragment is more than three-fourths, essentially a complete or almost complete shaft.

<https://doi.org/10.1371/journal.pone.0216733.t002>

Table 3. Definition of categories separating shaft fragments by circumference size according to Villa and Mahieu (1991) [38].

C1	Bone circumference is less than half of the original
C2	Bone circumference is more than half, but not a complete circumference, in at least a portion of the bone length
C3	Bone circumference is complete in at least one portion of the bone length

<https://doi.org/10.1371/journal.pone.0216733.t003>

- Notch form, three categories: fe1 (= symmetric to the fracture, longest depth is in the centre part of the notch when the diaphysis is observed from a vertical angle); fe2 (= asymmetric, longest depth of the notch is on the distal side) and fe3 (= asymmetric, longest depth is on the proximal part),
- Text column for additional observations.

Points illustrating all the percussion marks are placed in the centre of the observed impact recording anatomical landmarks and the drawings of the fragments, e.g., points representing notches are situated in the middle of what is regarded as the fracture edge of the percussion mark. Points representing the rest of the percussion marks are situated in the centre of the observed impact area. We do not consider that the origin of the impact is at the centre of each percussion mark, but this choice was essential for standardizing the drawing process. We chose point features over line and polygon features to standardize and facilitate visualization and to fully exploit GIS spatial pattern analyses.

Bone survivorship. The GIS software can calculate the area defined by the outline of a polygon; therefore, we could calculate the area of each drawn fragment. With this information, we adapted the equation from Abe *et al.* [16] to calculate the frequency of cortical bone survivorship for each element:

Sum of fragments surface / whole bone surface * 100 = preserved cortical bone surface %.

To illustrate cortical bone survivorship, we follow Marean's procedure for MNE calculations [13], to which we made modifications available with the more recent versions of ArcMap. Previous studies [13], [15], [18–20] mainly used grid (pixel) overlapping, which requires converting vector to raster files, making the process more time consuming. Our method, detailed in supplementary material, consists of directly overlaying polygons to calculate cortical bone survivorship.

Percussion mark frequency. The frequency of percussion marks was calculated in relation to the preserved area for each element of each series:

$$\text{Number of percussion marks/preserved bone}\%*100 = \text{percussion mark \%}$$

This equation is an adaption of the Abe *et al.* [16] equation for calculating cut mark frequency. It was developed to improve frequency calculations by taking into consideration the fragmentation problem. Abe *et al.* [16] state that by dividing the number of cut marks by the preserved surface area, cut mark frequencies would closely match the original frequencies. Thus, “we can correct the number of cutmarks by the amount of examined surface area, much as demographers standardize population size by estimating population density”. In the same way as Lyman [14], we do not agree that this formula can be used to estimate the frequency of marks that have been destroyed, but we consider that it is a fair estimation of the frequency of preserved marks.

Patterns and clusters. When confronted with visual spatial data, we inherently organize, group, differentiate and transform these data into information. “Mapping” them like some previous studies [33–34] might result in a sense of the overall pattern of features and their

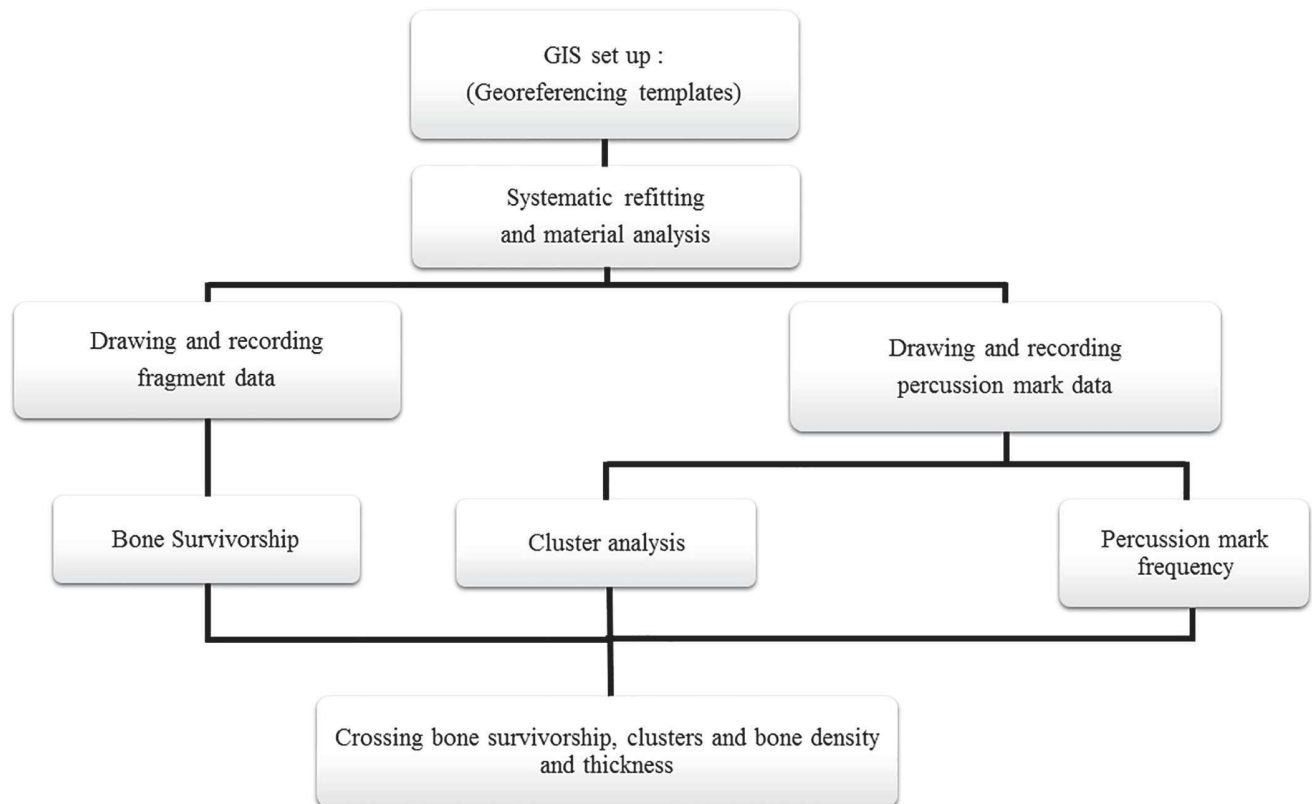


Fig 2. GIS stages for percussion mark analysis.

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associated values, but GIS spatial tools estimate concentrations of percussion marks by evaluating the interdistance between features. Calculating a statistic with GIS quantifies the pattern, which makes it easier to compare patterns and gain a better understanding of clusters (Fig 2). For this purpose, we used ArcGIS following spatial analyst and statistic tools:

Analysing patterns with Average Nearest Neighbour Distance (NND). We used the Average NND tool to test for significant spatial clusters following Parkinson and colleagues' method [18–20]. The tool calculates a nearest neighbour index based on the average distance from every point (percussion mark) to its nearest neighbouring feature. If the average distance between points is less than the average for a hypothetical random distribution, the distribution is considered to be clustered. If it is greater than one, the pattern is considered to be dispersed. The Z score represented by colour codes (S1 and S2 Tables) determines the value of probability that the observed pattern is significantly different from a random pattern [6]. The obtained values are sensitive to changes to the study area or changes to the Area parameter. The results are most appropriate when the study area is fixed. The defined area in which we tested for clusters is the bone surface calculated with the GIS polygon template. The NND was calculated for each view (anterior, posterior, medial and lateral) separately to accurately represent the surface area of the bone.

We used the NND tool to test for:

- Clusters taking into consideration all the percussion marks on a single bone element. We repeated this for the 10 bones in each series.
- Clusters taking into consideration one type of percussion mark (notch, pit and adhering flakes) for the whole series.

Visual representation of clusters/mapping clusters. To visually represent clusters, we followed Parkinson and colleagues' method [18–20] for the Kernel density tool and implanted a new method using the Optimized Hot Spot Analysis tool. The Kernel Density tool counts the number of modifications in an area. This tool uses the quadratic kernel formula described in Silverman [39] to fit a smoothly tapered surface to each point, which spreads out to a specified radius around the point. The highest cell value is at the point located in the centre of the spread, with the value tapering to zero at the boundary of the search radius distance. The sum of the intersecting spreads is then calculated for each cell in the output raster [6]. Kernel Density analysis is to some extent subjective as the analyst must input a search radius and cell size, which can significantly influence the results. The analysis can be carried out with only two points and still display a cluster zone.

On the other hand, Optimized Hot Spot analysis is more objective and uses the Getis-Ord G_i^* statistic to question the probability that a spatial distribution of values is random. To do this, the Optimized Hot Spot Analysis tool uses the average and median nearest neighbour calculations for aggregation and also to identify an appropriate scale of analysis. The tool computes each feature's average nearest neighbour distance and evaluates the distribution of all these distances. It defines high concentration zones (hot spots) and features that are more than a three-standard deviation distance away from their closest noncoincident neighbour, considered as locational outliers (cold spots). The limit of this tool, and the reason why we chose Kernel density for some analyses, is that Hot Spot analysis requires a minimum of 30 points to perform calculations. The numbers of observed percussion marks in our assemblage are not sufficient for testing all of our hypotheses with this tool.

Estimated cluster zones with the NND tool for separate bone elements are represented with Kernel density, for which we used a fixed search radius (0.12) and cell size (between 1.1 and 3.2). Analyses were not performed for areas with three impacts or less. Optimized Hot Spot analysis was used to estimate and illustrate clusters of all the percussion marks combined from the ten bones in a series.

We used Spearman's *rho* to test for correlations between several values. The coefficients were calculated, and their statistical significance was tested using PAST software [40].

Results

Experimental bone breakage remains

The breakage of the 40 cattle long bones resulted in 1 219 fragments, for which element and side were identified in 549 cases (44%) (Table 4). 701 fragments (56%) could not be identified, however, in terms of weight, the unidentified fragments represent only 1% of the total assemblage. The tibia series generated the highest rate of fragments (number of specimens produced: NSP), while the femur series produced the lowest, but these results are reversed in terms of number of identified and refitted specimens (NISP%). Among the NISP, 288 fragments (Table 4) bear at least one percussion mark, whereas among the unidentified fragments 71 have percussion marks. These latter are not included in our study.

The majority of NISP have a L1 and L2 length (Fig 3). Fragments with L1 length almost all have a C1 circumference, while the L2 fragments display more diverse circumferences. Percussion marks are most frequently identified on fragments with an L2 length and a C3 circumference (Fig 3). Spearman's test showed a positive correlation between the relative frequencies of shaft length and circumference for all identified specimens and the relative frequencies of percussion mark distribution of fragments bearing percussion marks (Humerus $\rho = 0.09622$ $P = 0$; Radius $\rho = 0.85353$ $P = 0.00041$, Femur $\rho = 0.97268$ $P = 0$ and Tibia $\rho = 0$ $P = 0.00488$).

Table 4. Presentation of the studied faunal series and number of percussion marks.

Bone Element	NSP ^a	NSP %	NISP ^b	NISP %	IND ^c	IND %	NISP with ^d PM	NISP with PM %	IND with PM	IND with PM %	NISP weight (g)	NISP weight (g) %	IND weight (g)	IND weight (g) %
Humerus	289	24%	108	37%	181	63%	66	81%	15	19%	11156	98%	179	2%
Radius-ulna	263	22%	119	45%	144	55%	61	79%	16	21%	8991	97%	108	3%
Femur	228	19%	130	51%	129	49%	68	80%	17	20%	18467	99%	98	1%
Tibia	439	36%	192	44%	247	56%	93	80%	23	20%	11207	98%	216	2%
Total	1219	100%	549	44%	701	56%	288	80%	71	20%	49821	99%	601	1%

^aNSP (number of specimens produced) = total number of fragments for each type of bone element

^bNISP (Number of identified and refitted specimens)

^cIND (unidentified specimens)

^dPM (percussion marks) = number of percussion marks identified on each type of bone element.

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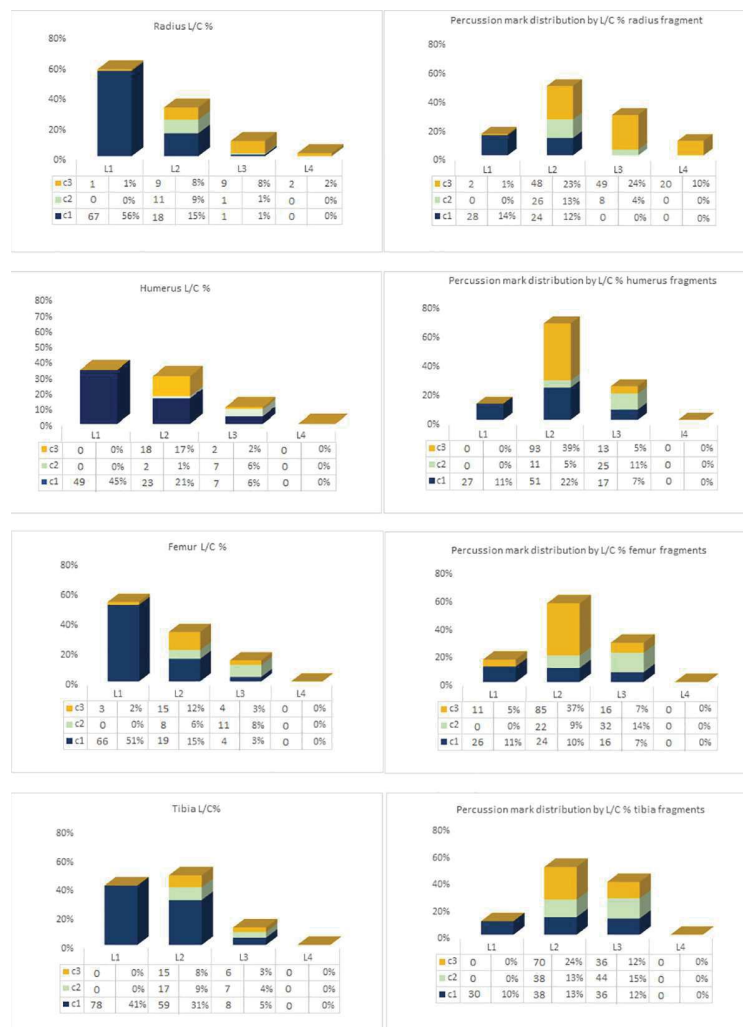


Fig 3. Distribution of NISP according to shaft length and circumference. Left column diagrams show relative frequencies of shaft length (L) and circumference (C) of all identified specimens; Right column diagrams show relative frequencies of percussion mark distribution according to relative frequencies of shaft length(L) and circumference (C) for specimens bearing percussion marks.

<https://doi.org/10.1371/journal.pone.0216733.g003>

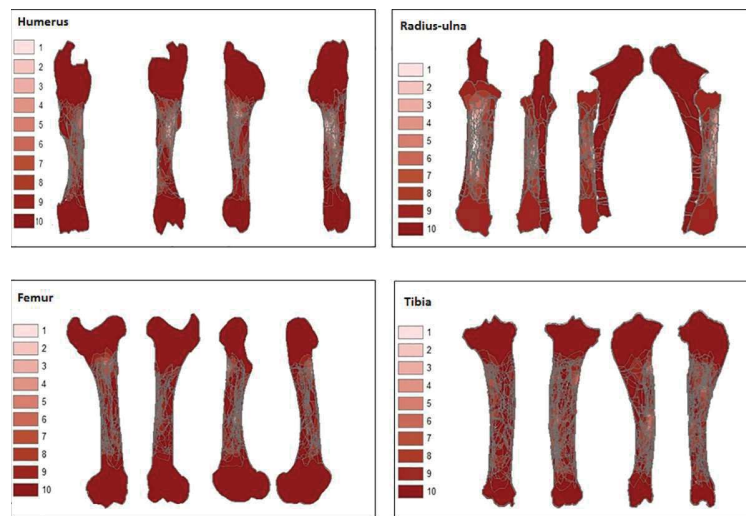


Fig 4. Bone survivorship composite of ten bone elements in a series for each bone element: Humerus, radius-ulna, femur and tibia represented in each side in the following order: Anterior, posterior, medial and lateral. Cortical preservation is indicated by shades of the colour red accompanied by a number from 1–10, darker shades and high numbers represent high cortical preservation.

<https://doi.org/10.1371/journal.pone.0216733.g004>

Bone survivorship

Results of cortical bone survivorship for each series of the four elements are represented in the form of a graduated colour map generated with GIS (Fig 4), accompanied by the rate of preservation (Tables 5–8). The maps represent composites of both left and right elements in the assemblage. The darker shaded areas indicate higher cortical survivorship. The results show that destruction resulting from percussion for marrow extraction affects exclusively the

Table 5. Series 1 humerus.

Humerus ref. n°	Lateralisation	NISP ^a	Cortical preservation % ^b	Total n° of blows ^c	Number of PM per side				Total n° of PM ^d	PM frequency ^e
					anterior	posterior	medial	lateral		
1–1	left	4	91%	110	2	1	4	11	18	20%
1–2	left	11	92%	78	3	0	7	10	20	22%
1–2	left	12	94%	93	0	8	9	2	19	20%
1–4	left	8	95%	38	0	2	8	9	19	20%
1–5	left	13	91%	40	3	4	4	12	23	25%
1–6	left	10	93%	50	13	4	9	4	30	32%
1–7	right	11	93%	51	11	1	3	3	18	19%
1–8	left	13	86%	50	4	3	8	11	26	30%
1–9	right	9	96%	32	8	4	7	4	23	24%
1–10	right	17	91%	30	9	15	15	2	41	45%
Mean		10.8	92%	57.2	5.3	4.2	7.4	6.8	23.7	26%
Standard deviation		3.4	2.8	27.2	4.6	4.4	3.4	4.1	7.2	8.1

^aNumber of identified specimens (NISP)

^bCortical preservation rate per element

^cTotal number of blows inflicted per element

^dTotal number of percussion marks (PM) per element and side

^ePM frequency calculated according to cortical preservation.

<https://doi.org/10.1371/journal.pone.0216733.t005>

Table 6. Series 2 radius.

Radius ref. n°	Lateralisation	NISP ^a	Cortical preservation % ^b	Total n° of blows ^c	Number of PM per side				Total n° of PM ^d	PM frequency ^e
					anterior	posterior	medial	lateral		
2-1	right	12	82%	115	12	3	6	4	23	30%
2-2	right	13	88%	88	18	8	0	3	28	33%
2-3	left	15	86%	48	8	12	0	0	19	23%
2-4	right	6	81%	94	10	3	0	3	14	20%
2-5	left	15	92%	29	16	2	0	0	17	20%
2-6	left	15	86%	108	13	11	0	5	27	34%
2-7	left	15	82%	131	14	9	0	3	25	32%
2-8	right	6	84%	71	6	4	1	6	16	20%
2-9	right	10	91%	67	17	4	0	2	22	25%
2-10	right	12	91%	53	9	6	0	1	15	17%
Mean		11.9	86%	80.4	12.3	6.2	0.7	2.7	20.6	25%
Standard deviation		3.5	4.1	32	4	3.6	1.9	2	5.2	6.3

^aNumber of identified specimens (NISP)

^bCortical preservation rate per element

^cTotal number of blows inflicted per element

^dTotal number of percussion marks (PM) per element and side

^ePM frequency calculated according to cortical preservation.

<https://doi.org/10.1371/journal.pone.0216733.t006>

diaphysis of long bones, but the zones concerned and the extent of destruction vary for the different elements.

Highest cortical survivorship was calculated for the ulna series with an average of 99%. This is due to the nearly absent medullar cavity and scarcity of bone marrow in the element. Due to this constant high preservation and the low number of observed percussion marks, the ulna

Table 7. Series 3 femur.

Femur ref. n°	Lateralisation	NISP ^a	Cortical preservation % ^b	Total n° of blows ^c	Number of PM per side				Total n° of PM ^d	PM frequency ^e
					anterior	posterior	medial	lateral		
3-1	left	14	94%	83	11	2	4	5	21	23%
3-2	left	11	98%	56	3	5	6	1	14	15%
3-3	left	11	94%	87	8	1	9	12	29	32%
3-4	right	8	95%	41	13	2	2	10	26	18%
3-5	left	11	95%	55	10	3	7	11	30	33%
3-6	right	23	95%	30	11	2	13	1	26	28%
3-7	right	9	97%	50	11	3	2	2	17	19%
3-8	right	11	97%	12	1	4	12	6	22	24%
3-9	right	17	94%	49	16	6	4	8	33	36%
3-10	right	15	93%	37	8	5	0	2	14	16%
Mean		13	95%	50	9.2	3.3	5.9	5.8	23.2	24%
Standard deviation		4.4	1.6	22.6	4.5	1.6	4.3	4.3	6.7	7.5

^aNumber of identified specimens (NISP)

^bCortical preservation rate per element

^cTotal number of blows inflicted per element

^dTotal number of percussion marks (PM) per element and side

^ePM frequency calculated according to cortical preservation.

<https://doi.org/10.1371/journal.pone.0216733.t007>

Table 8. Series 4 tibia.

Tibia ref. n°	Lateralisation	NISP ^a	Cortical preservation % ^b	Total n° of blows ^c	Number of PM per side				Total n° of PM ^d	PM frequency ^e
					anterior	posterior	medial	lateral		
-1	left	22	92%	16	6	7	9	4	26	28%
4-2	left	19	96%	13	1	8	3	6	18	19%
4-3	left	16	92%	27	7	15	0	4	26	28%
4-4	left	20	98%	15	3	8	5	10	26	26%
4-5	left	21	90%	26	7	8	2	6	23	25%
4-6	right	22	93%	26	21	16	6	4	47	50%
4-7	right	24	90%	28	22	3	5	2	32	35%
4-8	left	14	94%	26	4	6	7	6	23	24%
4-9	right	18	95%	21	11	12	6	6	35	37%
4-10	right	16	95%	21	14	13	4	5	36	38%
Mean		19.2	94%	21.9	9.6	9.6	4.7	5.3	29.2	31%
Standard deviation		3.2	2.6	5.5	7.2	4.2	2.6	2.1	8.4	9

^aNumber of identified specimens (NISP)

^bCortical preservation rate per element

^cTotal number of blows inflicted per element

^dTotal number of percussion marks (PM) per element and side

^ePM frequency calculated according to cortical preservation.

<https://doi.org/10.1371/journal.pone.0216733.t008>

series was excluded from further analysis. Average cortical preservation for the rest of the elements is as follows: hindlimb bones show a preservation rate of 95% for the femur and 94% for the tibia series. For the front limbs, the humerus series presents an average of 92%, while the radius series shows an average of 86%. The most recurrently affected zone for all elements is the proximal to central part of the diaphysis, but this is not systematic for all sides. For the humerus and tibia series, zones of low preservation are rare on the anterior side. The femur posterior side shows no zones with low preservation. The radius series shows zones of low cortical preservation on all four sides.

Patterns and cluster distributions

A total of 967 percussion marks were identified, comprising 237 in the humerus series, 206 in the radius, 232 in the femur and 292 in the tibia series. The most recurrent percussion marks in our sample are notches, pits and adhering flakes (Table 9). Fig 5 shows obvious concentration zones for some percussion marks, e.g., the proximal part of the femur’s anterior side shows an important cluster of adhering flakes. However, it is more difficult to identify other marks that seem more dispersed or mixed up with others.

We compared the number of inflicted blows and percussion mark frequency to see if there is a correlation between the two values (Tables 5–8). None of the elements showed statistically significant correlation for the two variables (Humerus $\rho = 0.56618$ and $P = 0.08797$; Radius-Ulna $\rho = 0.61968$, $P = 0.05602$; Femur $\rho = 0.06667$ $P = 0.85481$ and Tibia $\rho = 0.29632$ $P = 0.40578$).

We also wanted to determine whether the experimenter found a more effective technique for breaking the bone over time and after several bone element breakages. For this, we ran a Spearman’s correlation test between the total number of inflicted blows and the number of experimental attempts (from 1 to 10) (Tables 5–8) (Fig 6). Results showed a significant negative correlation for the humerus ($\rho = -0.77204$ and $P = 0.00888$) and femur ($\rho = -0.72121$ and

Table 9. Distribution of percussion marks by type of mark and element aspect.

Element aspect	Type of percussion mark	Humerus	Radius	Femur	Tibia	Total
Anterior	Notch	7 (13%)	32 (29%)	11 (12%)	34 (35%)	84 (24%)
	Pit	18 (34%)	16 (14%)	32 (35%)	45 (47%)	111 (31%)
	^a Adh. Flake	13 (25%)	39 (35%)	34 (37%)	14 (15%)	100 (28%)
	^b Crushing	4 (8%)	6 (5%)	8 (9%)	1 (1%)	19 (5%)
	^c C. c. scar	11 (21%)	19 (17%)	7 (8%)	2 (2%)	39 (11%)
Posterior	Notch	7 (17%)	17 (28%)	5 (15%)	31 (32%)	60 (26%)
	Pit	18 (43%)	18 (30%)	18 (55%)	51 (53%)	105 (45%)
	Adh. Flake	10 (24%)	14 (23%)	3 (9%)	9 (9%)	36 (16%)
	Crushing	0	6 (10%)	0	0	6 (3%)
	C. c. scar	7 (17%)	5 (8%)	7 (21%)	5 (5%)	24 (10%)
Medial	Notch	9 (12%)	5 (71%)	21 (36%)	10 (21%)	45 (24%)
	Pit	28 (38%)	1 (14%)	22 (37%)	19 (40%)	70 (37%)
	Adh. Flake	19 (26%)	1 (14%)	5 (8%)	14 (30%)	39 (21%)
	Crushing	3 (4%)	0	2 (3%)	1 (2%)	6 (3%)
	C. c. scar	15 (20%)	0	9 (15%)	3 (6%)	27 (14%)
Lateral	Notch	20 (29%)	11 (41%)	11 (23%)	18 (34%)	60 (31%)
	Pit	11 (16%)	9 (33%)	11 (23%)	25 (47%)	56 (29%)
	Adh. Flake	24 (35%)	4 (15%)	18 (38%)	6 (11%)	52 (27%)
	Crushing	3 (4%)	0	5 (10%)	2 (4%)	10 (5%)
	C. c. scar	10 (15%)	3 (11%)	3 (6%)	2 (4%)	18 (9%)

Abbreviations

^aAdh. Flake = Adhering flakes

^bCrush = Crushing mark

^cC.C. scar = Cortical conchoidal scar

<https://doi.org/10.1371/journal.pone.0216733.t009>

P = 0.01857), which means that the number of blows required to breach the cavity and fully extract the marrow tends to decrease from the first attempt to the last. Non-significant correlation was found for the radius ($\rho = -0.22424$ and $P = 0.5334$) and tibia series ($\rho = 0.32004$ and $P = 0.36732$).

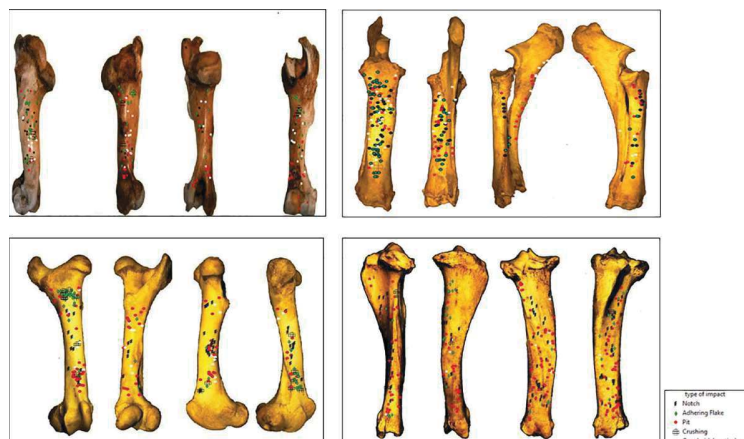


Fig 5. Distribution of percussion marks along the long bone elements (humerus, radius-ulna, tibia and femur), divided by type of percussion mark (each percussion mark is indicated with a specific symbol).

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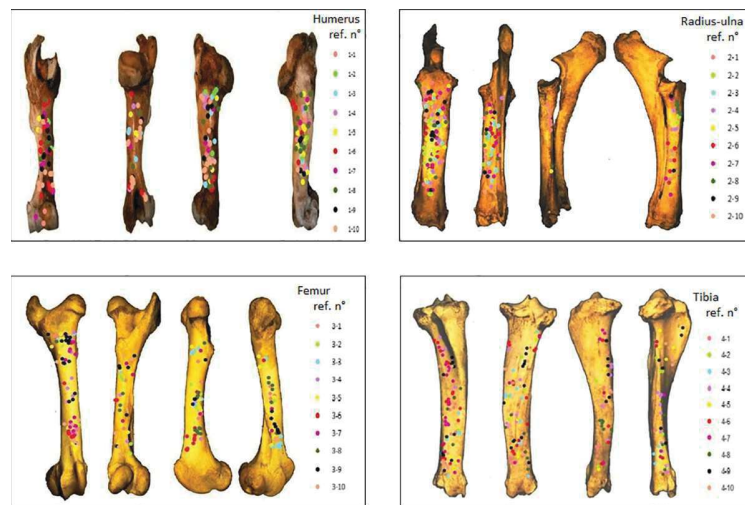


Fig 6. Distribution of percussion marks along the long bone elements, with different colours representing the marks made by different experimental attempts.

<https://doi.org/10.1371/journal.pone.0216733.g006>

Testing for clusters per element. Using the GIS average NND tool we determined the existence of cluster zones per side on each bone element (S1 Table). Results show percussion mark clusters on 37 out of 40 long bone elements. Only one radius element (ref n° 2–9) and two tibia elements (ref. n° 4–2 and 4–5) showed no significant clusters.

To illustrate the identified cluster zones, we used the kernel density tool (Figs 7–10), which shows significant variation in the distribution of these clusters across the different elements. The distribution of number of clusters by side (Anterior, Posterior, Medial and Lateral) and portion of the shaft (Proximal, Central, Distal) is calculated and summarized in Fig 11.

In the humerus series, clusters are most recurrent on the lateral and medial sides (Fig 7), (S1 Table). The most impacted zones on the lateral side are the central and distal parts of the diaphysis, and the proximal and distal parts of the diaphysis on the medial side. The identified clusters on the posterior and anterior sides are randomly distributed on the diaphysis (Fig 11). The radius series clusters are most frequently identified on the anterior side of the diaphysis (Fig 8), (S1 Table), with the highest rate on the central part (Fig 11). Posterior side clusters are less recurrent, but are consistent on the proximal and central parts of the diaphysis. The lateral and medial sides rarely show cluster zones, but the few representative zones are situated on the proximal part of the diaphysis. Femur clusters are most recurrent on the anterior and medial sides (Fig 9), (S1 Table). The anterior side clusters are located on the proximal and distal parts of the diaphysis, and the medial side clusters on the central and distal parts. Clusters on the posterior and lateral sides are less frequent and equally distributed on the shaft. Like the radius series, tibia clusters are most recurrent on the anterior and posterior sides, although with a lower rate. No single portion of the diaphysis can be differentiated (Fig 11).

Cluster patterns were identified for all the 10 bones of each series combined using Optimized hot spot analysis (Fig 12). The results represent a synthesis of the individual Kernel density map elements and reveal results corresponding to Fig 11. The advantage of Hot spot analysis is that it balances out the degree of clustering by taking into consideration the different views for the analysis.

In sum, the proximal and distal parts of the humerus diaphysis are cold spots, except for the medial side. The whole humerus diaphysis represents a hot spot zone for the lateral side.

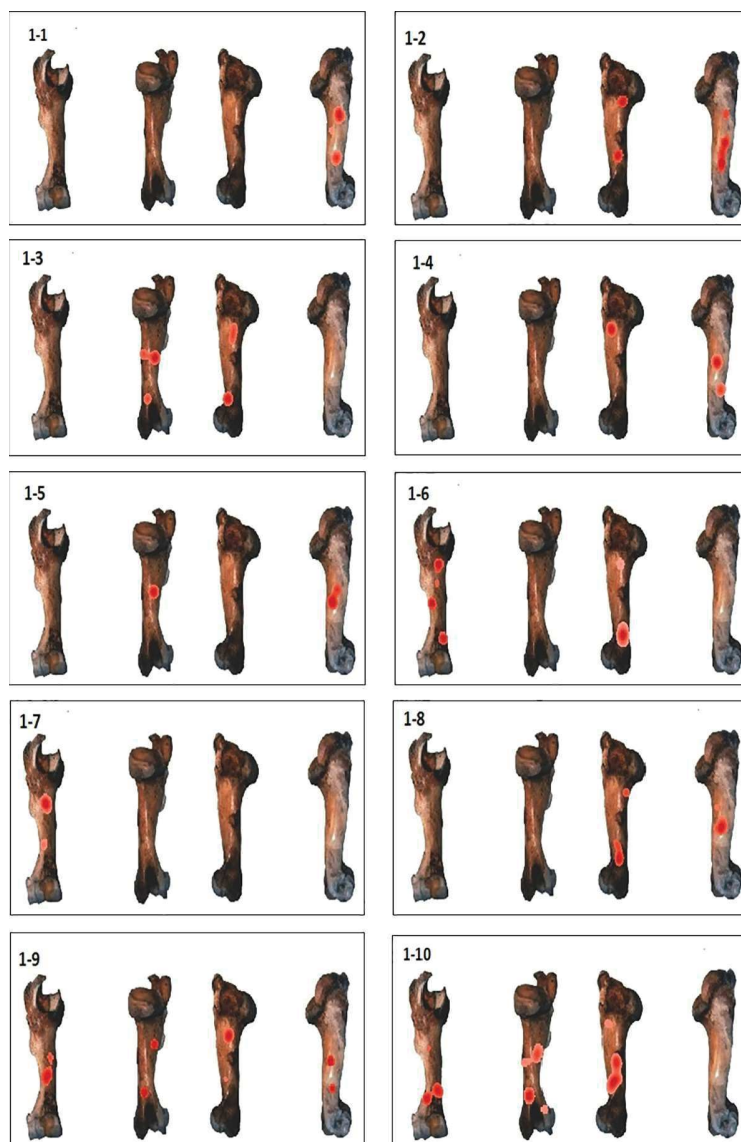


Fig 7. GIS Kernel density analysis results of percussion mark distribution on the four aspects for each humerus. Dark red areas indicate the highest concentrations of percussion marks.

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Anterior and posterior side hot spot zones display lower confidence levels of clustering (Fig 12) and correspond to the central to distal parts of the diaphysis.

The combined radius series percussion mark cluster analysis defines a high confidence hot spot zone on the anterior side of the diaphysis. The posterior side shows a well-defined hot spot zone on the proximal and central shaft. The lateral medial sides are identified as cold spots.

For the femur series, the well-defined hot spot zones are located on the anterior, proximal and distal parts of the diaphysis. Other significant hot spots are located on the medial central to distal part of the shaft and the distal part of the lateral shaft.

The most impacted sides for the tibia series are the anterior and posterior sides. However, the whole diaphysis is affected and the most impacted zone is the distal part of the shaft. The same zone is impacted for the lateral side as well.

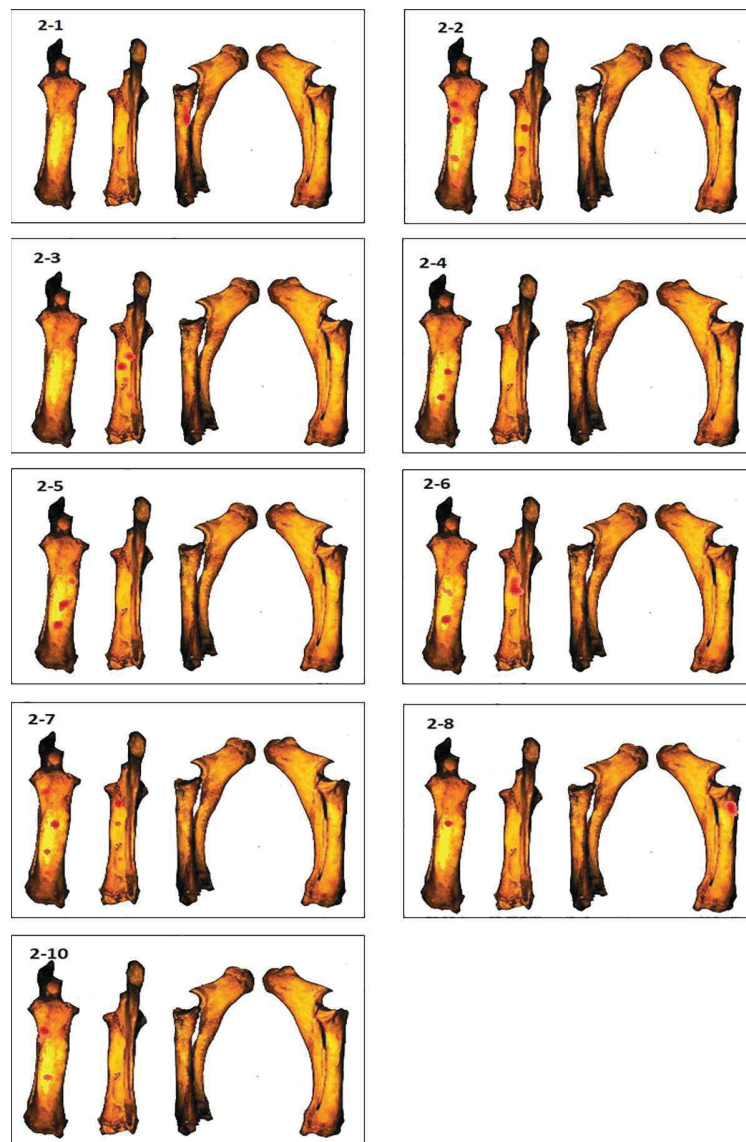


Fig 8. GIS Kernel density analysis results of percussion mark distribution on the four aspects for each radius. Dark red areas indicate the highest concentrations of percussion marks.

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Testing for clusters per type of percussion mark. The three most recurrently identified percussion marks for the whole sample (notches, pits and adhering flakes) were tested using the NND tool (S2 Table) for clusters separately. Kernel density results show that while the overall patterns were quite distinct between the elements when all percussion marks were considered (Fig 12), similarities appear when we consider a single type of percussion mark. Notch clusters are more variable but frequently appear in the central part of the shaft (Fig 13). Pit clusters, with the exception of the radius series, are most recurrent on the distal part of the shaft (Fig 14). Adhering flake clusters are most recurrent in the proximal and distal parts of the shaft for all elements (Fig 15).

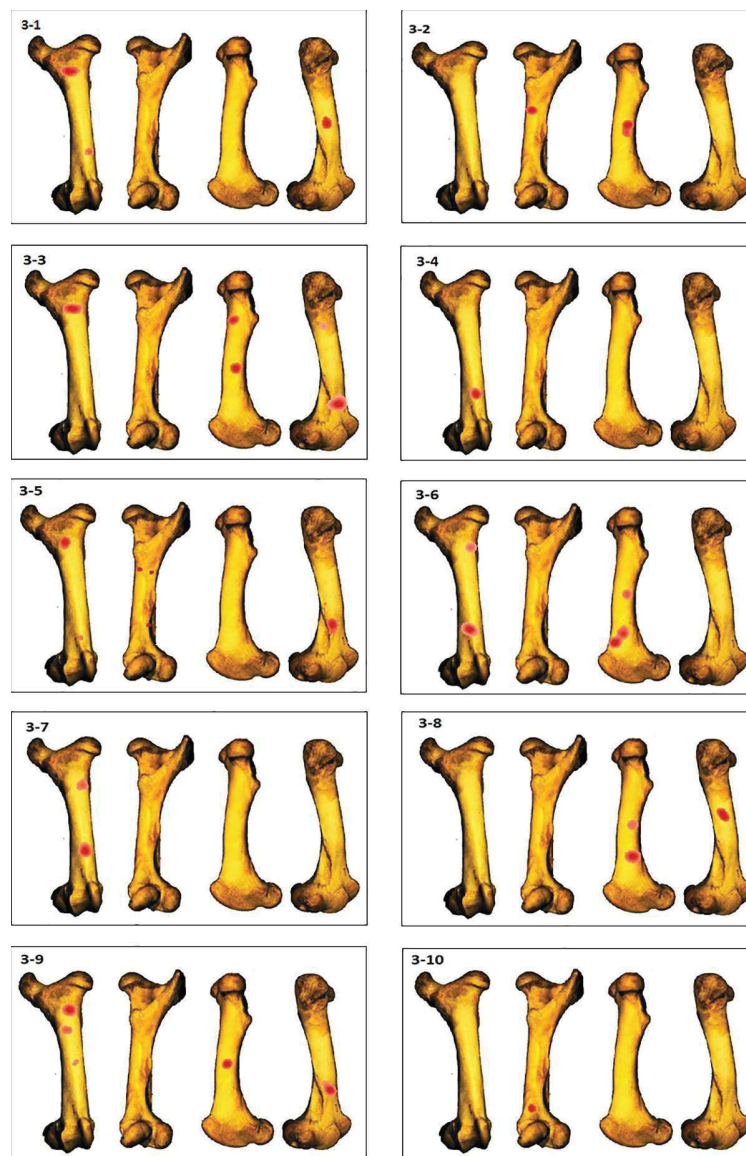


Fig 9. GIS Kernel density analysis results of percussion mark distribution on the four aspects for each femur. Dark red areas indicate the highest concentrations of percussion marks.

<https://doi.org/10.1371/journal.pone.0216733.g009>

Discussion

Standardizing the documentation process

GIS software can be adapted and can provide valuable insights for non-geographical data, but it is important to clarify that this application has certain limitations. For the time being, georeferenced and uniformized templates constitute an appropriate option for establishing a workspace in GIS. However, this adjustment deforms all metric measurements, and therefore the drawings made using the software are not an exact replication. To adjust these values, most of the calculations can be expressed in frequency rates. Considering this, we underline the need for standardization and clear protocols for recording spatial data, i.e., precise criteria to define the placement of points (percussion marks) or outlines of polygons (fragments). If this is

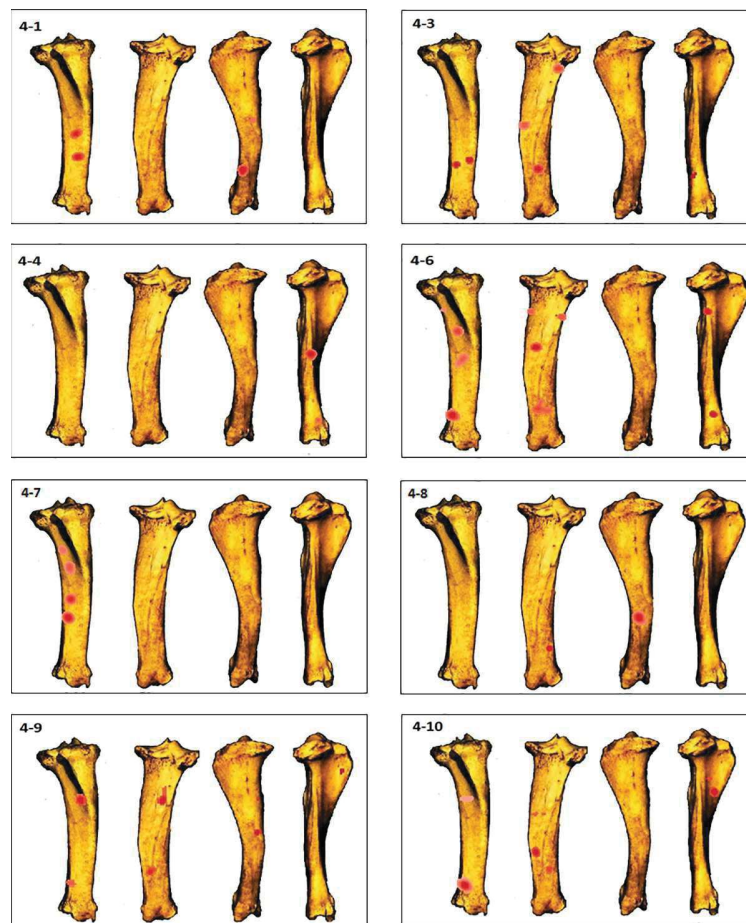


Fig 10. GIS Kernel density analysis results of percussion mark distribution on the four aspects for each tibia. Dark red areas indicate the highest concentrations of percussion marks.

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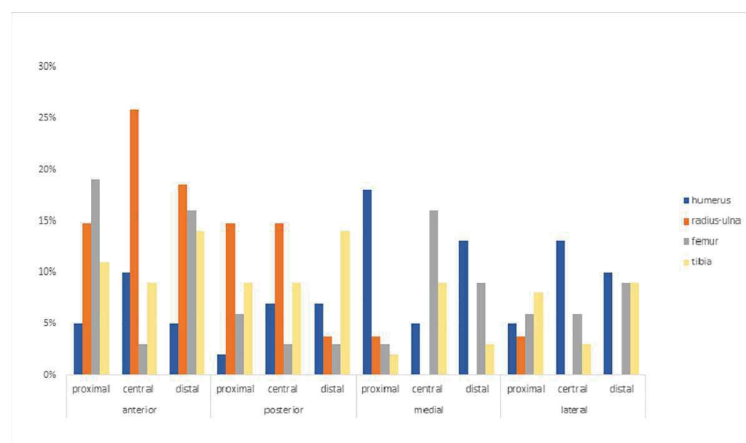


Fig 11. Summary of Kernel density cluster distribution according to side and shaft portion.

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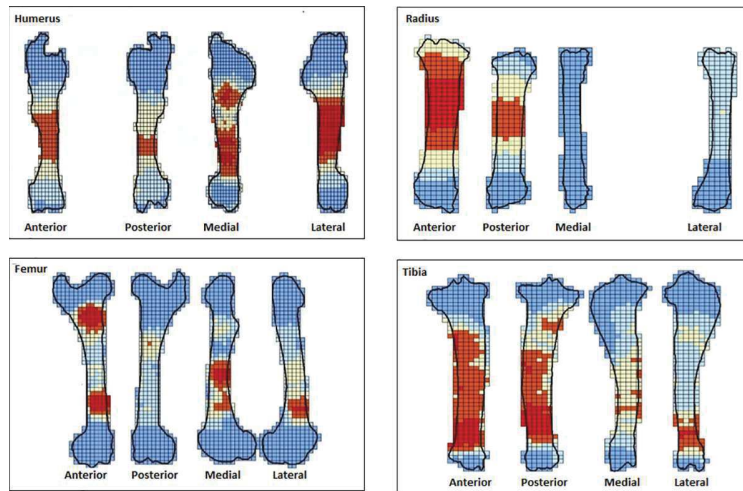


Fig 12. Optimized Hot spot analysis of combined percussion marks from the ten bone elements in each series.

<https://doi.org/10.1371/journal.pone.0216733.g012>

carried out correctly, the ArcGIS database can be used to organize and analyse big data and provide venues to explore a variety of questions in a short amount of time. For this study, we precisely calculated the examined surface and evaluated concentrations of percussion marks based on their spatial interdistances and not on imposed predefined portions. The principal advantage of GIS is the visual representation of the results. “Bone maps” of survivorship and clusters capture and convey information in a particularly insightful manner for the purpose of this study. This becomes clear when we compare figures with simply mapped features (Figs 5 and 6) to mapped clusters (Figs 7–12).

Fragmentation and bone survivorship

Bone survivorship analysis evaluates bone loss, which is usually neglected in experiments. Here, all the fragments were directly identified as belonging to each element during the

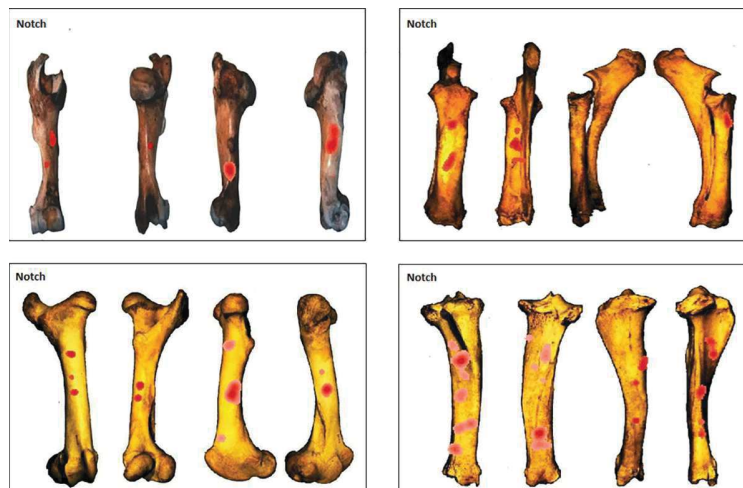


Fig 13. GIS Kernel density analysis results for notch distribution on the four aspects for each bone element series. Dark red areas indicate highest concentrations of notches.

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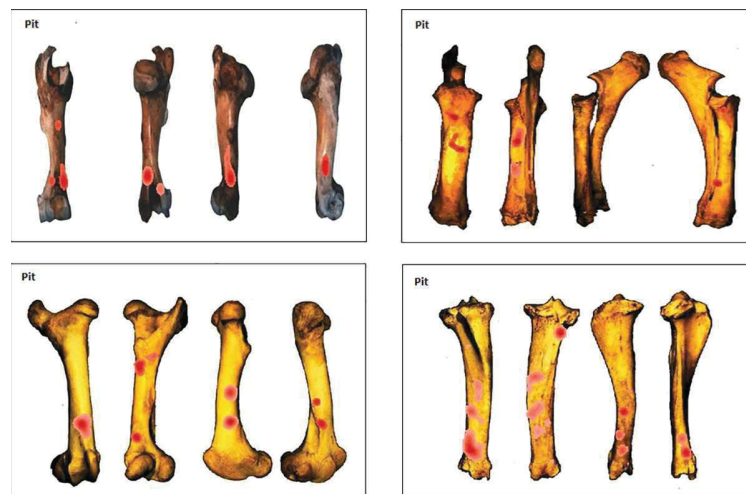


Fig 14. GIS Kernel density analysis results of pit distribution on the four aspects for each bone element series. Dark red areas indicate highest concentrations of pits.

<https://doi.org/10.1371/journal.pone.0216733.g014>

experiment and were collected, and in theory we should have approximately 100% bone survivorship, but this is not the case, due to several factors, referred to as laboratory taphonomy by Costamagno [41] and Bartram and Marean [42]. Costamagno discusses loss due to sampling procedures and analytical methods. In our case, part of the loss is, as mentioned before, due to the exclusive selection of the fragment's cortical preserved surface. The range of fragment material loss is 5–14%. The weight of undetermined fragments does not exceed 3% in any element series and does not explain the low 86% average survivorship for the radius series. Other loss derives from putting the material through the different phases, starting from the experiment to the final step of the analysis. During breakage of the bone, one percent is lost immediately due to the crushing effect and the parting distance of small-sized fragments from the experiment spot. During the cleaning process, a certain number of fragments are lost or mixed up because of the large quantity of experimental material (400 bones), and cannot be

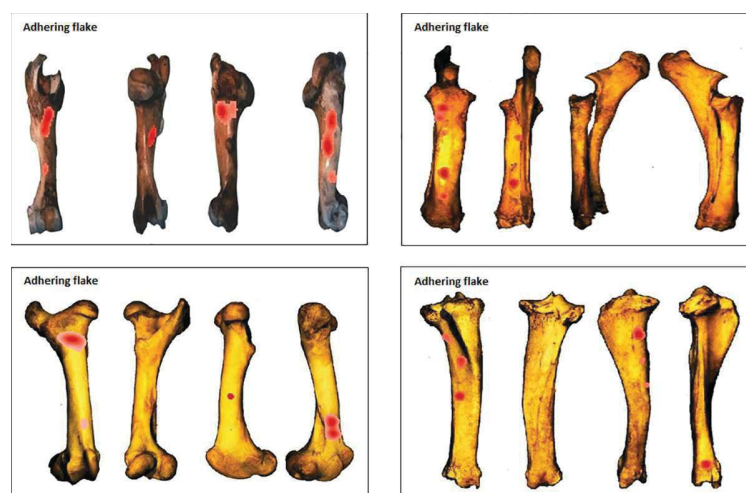


Fig 15. GIS Kernel density analysis results for adhering flake distribution on the four aspects for each bone element series. Dark red areas indicate highest concentrations of adhering flakes.

<https://doi.org/10.1371/journal.pone.0216733.g015>

reattributed to bones. The GIS method for bone survivorship proved to be effective because we not only calculate the percentage of the examined surface, but we can also visualize it and cross this data with percussion patterns and bone mineral properties. Crossing bone survivorship with clusters and patterns proved to be a better solution than the frequently used graphic representation of the relationship between the total recovered bone portions and bone portions with percussion marks. Indeed, it provides a visual representation of both and can reveal possible connections.

For calculating the fragmentation of our sample, we follow Marshall and Pilgram's model of fragmentation effect [43]. As fragmentation intensity increases, the NISP decreases because fragments become so small as to be unidentifiable. The highest fragmentation rates in this sample were estimated for the tibia and humerus series, which showed high NSP but lower NISP rates (Table 4). However, this has no impact on cortical preservation, i.e., the examined surface did not decrease in size.

Pickering and Egeland's hammerstone percussion experiment on deer humeri and radii elements, which also involved fracturing bones to a sufficient extent for complete marrow extraction, reports significantly higher fragmentation for the radii elements [28]. Moclan and Dominguez-Rodrigo [34] report similar results although the difference in fragmentation from their sample is less significant. Pickering and Egeland attribute this difference to the higher number of blows impacted on the radii to expose the medullary cavity (mean per individual radius = 6, humerus = 2). On the contrary, in our sample, the tibia series has the lowest number of impacted blows (mean per series = 21). In our experiment, the highest number of impacted blows was recorded for the radius series (mean per series: radius = 83), but this did not result in higher fragmentation, although it did result in the loss of 14% of the examinable surface, as shown by the bone survivorship results.

This difference can be explained by the variance in the concepts of the two experiments. The significant difference in the number of inflicted blows in these two experiments for the same bone element is due to the use of bones from different species. Indeed, deer bone elements are more gracile than cattle bones, and contrary to Pickering and Egeland's experiment, volunteers in this study are novices or unexperienced in hammerstone percussion. Moreover, graduated bone survivorship "maps" (Figs 4–7) demonstrate that there is no constant fracture pattern. The numerous fragment outlines intersect, but rarely overlap, demonstrating multiple variable fracturing outcomes for the same bone element, even with standardization and systematization.

Percussion mark clusters

Percussion marks were analysed per type of mark and per element with the NND and represented with the Kernel Density tool. The drawback with these tools is that illustrations and analyses are performed on a four-sided image of a bone element, which ignores the 3D shape of the bone. NND and Kernel density calculations are limited to one aspect of an element at a time, meaning that no connections can be made between the different aspects of the element (anterior, posterior, medial and lateral). This can be overcome with Optimized Hot Spot analysis. However, this tool requires a minimum of 30 features to conduct the analysis.

Cluster zones were examined in order to assess the degree of preservation of elements. Bone survivorship results show that zones with low cortical preservation (Figs 4–7) correspond well to clusters (hot spots) (Fig 12). Percussion marks themselves are read as negatives on the bone surface, i.e., zones that damage the cortical surface of the bone. In addition, when the experimenter inflicts additional blows to completely breach the shaft on a zone already bearing percussion marks, he/she obliterates them by crushing or reducing the size of the fragments to such an extent

that they are no longer identifiable. In sum, the process of bone breakage itself reduces our ability to completely grasp marrow extraction by examining the material. Hence, during bone marrow extraction by humans, before sedimentary processes start acting, the most impacted zones by percussion are the least preserved zones, even in controlled conditions.

Abe *et al.* [16] state that “fragmentation generally decreases the number of cut marked fragments and cut mark counts relative to total fragments” (Abe *et al.* 2002:649 Abe *et al.* (2002:657) and that a “key assumption that all zooarchaeologists make is that more intensive cutting (more cutting actions) results in higher frequencies of cutmarks on the bone surface.” This is generally assumed for percussion marks as well. However, experiments by Egeland [44] found that there is a statistically significant negative correlation between the number of hammerstone blows and percussion mark frequency ($r = -0.234$, $P = 0.045$). In our sample, none of the elements showed statistically significant correlations for the two variables (Humerus $\rho = 0.56618$ and $P = 0.08797$; Radius-Ulna $\rho = 0.61968$ and $P = 0.05602$; Femur $\rho = 0.06667$ and $P = 0.85481$, Tibia $\rho = 0.29632$ $P = 0.40578$). We suspect that this is because the number of blows inflicted in Egeland is very low as experimenters had previous knowledge of hammerstone percussion. Several authors have underlined that professional butchers [14–30] or people practicing marrow extraction leave fewer traces on bone surfaces as their goal is to finish the task with the least possible effort. A person experimented in marrow extraction would be more efficient and would break the bone with fewer blows than a novice.

Intuitive fracturing

We compared cortical bone survivorship and cluster analysis with Lyman’s density data [45] and Barba and Dominguez’s cortical thickness [46] data to evaluate whether the least preserved and most impacted surfaces can be correlated with fragile spots on the bone. GIS graduated maps of density and thickness measurements (S1 Fig) resulted in similar divisions and Spearman’s test showed a positive correlation for both values. Results showed that the least dense and least thick parts of the bone do not particularly correspond to low cortical preservation or cluster zones. The choice of impact points was not influenced by the bone’s mineral properties but possibly by the bones physical, morphological and physiological characteristics. These factors could result in unintentional patterns on the bone that may not be entirely guided by the individual’s intention but rather by the animal’s anatomy. For instance, the medial side of the humerus is flatter than the other sides, and thus more easily stabilized on the anvil. The video recording of the experiment showed that during the first blows to each humerus element, the volunteer recurrently put the medial side on the anvil and impacted the lateral side. In the final impacts, the individual flips the bone and impacts the medial side to completely break the shaft. That is why we see preferential sides when all percussion marks are combined (Fig 12). When we take into consideration a single type of percussion mark, the bone element’s morphology can also explain why preferential portions of the shaft were impacted. Notch clusters are most recurrent in the central portion of the shaft (Fig 13), where the hammerstone can strike the bone easily without slipping from the bone surface. Pit clusters appear on the distal part of the shaft (Fig 14), where the curved surface and epiphyses present obstacles for hammerstone impact. At this stage of the analysis, we cannot confirm or refute these statements, as every series was broken by a single individual. The analysis of the rest of the experimental material will help to check morphological conditioning factors.

Conclusions

Through the study of this experimental sample, we observed the effectiveness of the GIS-based method and drew some conclusions relative to intuitive bone fracturing.

Bone morphology plays an important role in experimental bone breakage by beginners. Adaptation to the shape of the bone results in repetitive gestures and percussion mark pattern. These patterns are not perfectly standardized, but they show cluster zones of percussion marks for each bone element. Bone survivorship and a visual presentation of the examined surface show important links. Results in controlled experimental conditions show that the most impacted zones were the least preserved, and bone loss in the same zones would be much higher after the actions of taphonomic agents. Therefore, in archaeological assemblages, the connection between the examined surface and the pattern needs to be examined and clarified before making conclusions on the concentration and patterns of marks.

This study shows the potential of GIS spatial statistical abilities to improve existing quantifying methods and visually presenting the obtained results. The software provides a convenient system for stocking and analysing large data assemblages while considering the spatial link for input information. Analyses of modern experimental bone assemblages using the GIS method can provide valuable and easily shared analogues with which to compare percussion mark distributions in archaeological assemblages.

This study can also be used as a complementary experiment to Parkinson's studies [18–20] and assist in the determination of bone agent modifiers and their order of access, by adding hominid-induced marks to the large canid and felid database. It also underlines the importance of crossing bone survivorship with mark distribution, especially for archaeological assemblages, where taphonomic agents would considerably decrease the observable cortical surface. Crossing the two in a visual manner can relativize and provide information on the extent of fragmentation effects on percussion mark frequency.

Supporting information

S1 Table. GIS Cluster analysis for percussion marks for the four bone elements (humerus, radius, femur and tibia) using average nearest neighbour. Analysis was performed on the four aspects of the elements. The distance between each percussion mark and its nearest neighbour was measured. The nearest neighbour index (NNI) is the observed distance divided by the average expected distance in a hypothetical random distribution. If the NNI is less than 1, the pattern is considered clustered. If the NNI is greater than 1, the trend is towards dispersion. Colour codes (Z score) indicate the degree of clustering or dispersion. Null values signify that the number of counted marks was 3 or less.

(PDF)

S2 Table. GIS Cluster analysis for individual type of percussion marks for the four bone elements (Humerus, Radius, Femur and Tibia) using average nearest neighbour. Analysis was performed on the four aspects of the elements. The distance between each percussion mark and its nearest neighbour was measured. The nearest neighbour index (NNI) is the observed distance divided by the average expected distance in a hypothetical random distribution. If the NNI is less than 1, the pattern is considered clustered. If the NNI is greater than 1, the trend is towards dispersion. Colour codes (Z score) indicate the degree of clustering or dispersion. Null values signify that the number of counted marks was 3 or less.

(PDF)

S1 Fig. Graduated maps of thickness measurements according to Barba et al (2005). Darker blue zones represent the thicker portions of the bone.

(PDF)

S1 Protocol. GIS percussion pattern analysis method.

(PDF)

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Annexes 1

Supplementary data

Supplementary data 1: Table GIS Cluster Analysis for percussion marks for the four bone elements (Humerus, Radius, Femur and Tibia) using Average Nearest Neighbour.

<i>Humerus</i>												
<i>ref. number</i> <i>1</i> <i>(1-10)</i>	<i>anterior</i>			<i>posterior</i>			<i>medial</i>			<i>lateral</i>		
	<i>p value</i>	<i>z value</i>	<i>NNR</i>	<i>p value</i>	<i>z value</i>	<i>NNR</i>	<i>p value</i>	<i>z value</i>	<i>NNR</i>	<i>p value</i>	<i>z value</i>	<i>NNR</i>
<i>notch</i>	0.02612	-2.2244	0.5889	0.005007	-2.8066	0.26647	0.051413	-1.9480	0.60058	0	-5.0347	0.39623
<i>pits</i>	0.000002	-4.7462	0.4152	0	-5.1272	0.30800	0	-5.9376	0.35283	0.000047	-4.0692	0.29098
<i>adhering flakes</i>	0.000064	-3.9985	0.4204	0.03628	-2.0938	0.63518	0.000411	-3.5332	0.56469	0	-6.3233	0.35177
<i>Radius</i>												
<i>ref. number</i> <i>2</i> <i>(1-10)</i>	<i>anterior</i>			<i>posterior</i>			<i>medial</i>			<i>lateral</i>		
	<i>p value</i>	<i>z value</i>	<i>NNR</i>	<i>p value</i>	<i>z value</i>	<i>NNR</i>	<i>p value</i>	<i>z value</i>	<i>NNR</i>	<i>p value</i>	<i>z value</i>	<i>NNR</i>
<i>notch</i>	0.002293	-3.049355	0.718225	0.000033	-4.153019	0.473488	0.739182	-0.332963	0.928846	0.003008	-2.96692	0.532396
<i>pits</i>	0.005216	-2.793406	0.645857	0.000038	-4.119638	0.550981	Null	Null	Null	0.04694	-1.986842	0.671578
<i>adhering flakes</i>	0	-5.66379	0.525928	0.004654	-2.830062	0.604632	Null	Null	Null	0.282578	1.074547	1.280843
<i>Femur</i>												
<i>ref. number</i> <i>3</i> <i>(3-10)</i>	<i>anterior</i>			<i>posterior</i>			<i>medial</i>			<i>lateral</i>		
	<i>p value</i>	<i>z value</i>	<i>NNR</i>	<i>p value</i>	<i>z value</i>	<i>NNR</i>	<i>p value</i>	<i>z value</i>	<i>NNR</i>	<i>p value</i>	<i>z value</i>	<i>NNR</i>
<i>notch</i>	0.001855	-3.112576	0.509439	0.009957	-2.577308	0.397509	0	-6.026614	0.312563	0.002212	-3.060236	0.517688
<i>pits</i>	0	-5.362333	0.504495	0.000208	-3.708988	0.543029	0	-5.116608	0.429783	0.000502	-3.479535	0.451604
<i>adhering flakes</i>	0	-6.452415	0.421568	Null	Null	Null	0.007663	-2.666581	0.37664	0	-6.140227	0.243485
<i>Tibia</i>												
<i>ref. number</i> <i>3</i> <i>(4-10)</i>	<i>anterior</i>			<i>posterior</i>			<i>medial</i>			<i>lateral</i>		
	<i>p value</i>	<i>z value</i>	<i>NNR</i>	<i>p value</i>	<i>z value</i>	<i>NNR</i>	<i>p value</i>	<i>z value</i>	<i>NNR</i>	<i>p value</i>	<i>z value</i>	<i>NNR</i>
<i>notch</i>	0	-6.674831	0.401630	0.000001	-4.860112	0.543717	0.00003	-4.17716	0.309521	0.00025	-3.662662	0.548737
<i>pits</i>	0	-6.697298	0.478130	0.000001	-4.99054	0.634715	0.000203	-3.715334	0.554456	0.000379	-3.554238	0.628426
<i>adhering flakes</i>	0.000859	-3.332895	0.534385	0.849513	0.164277	1.028624	0.000149	-3.793439	0.470046	0.015772	-2.414143	0.484823

Dispersed 99%
confidence

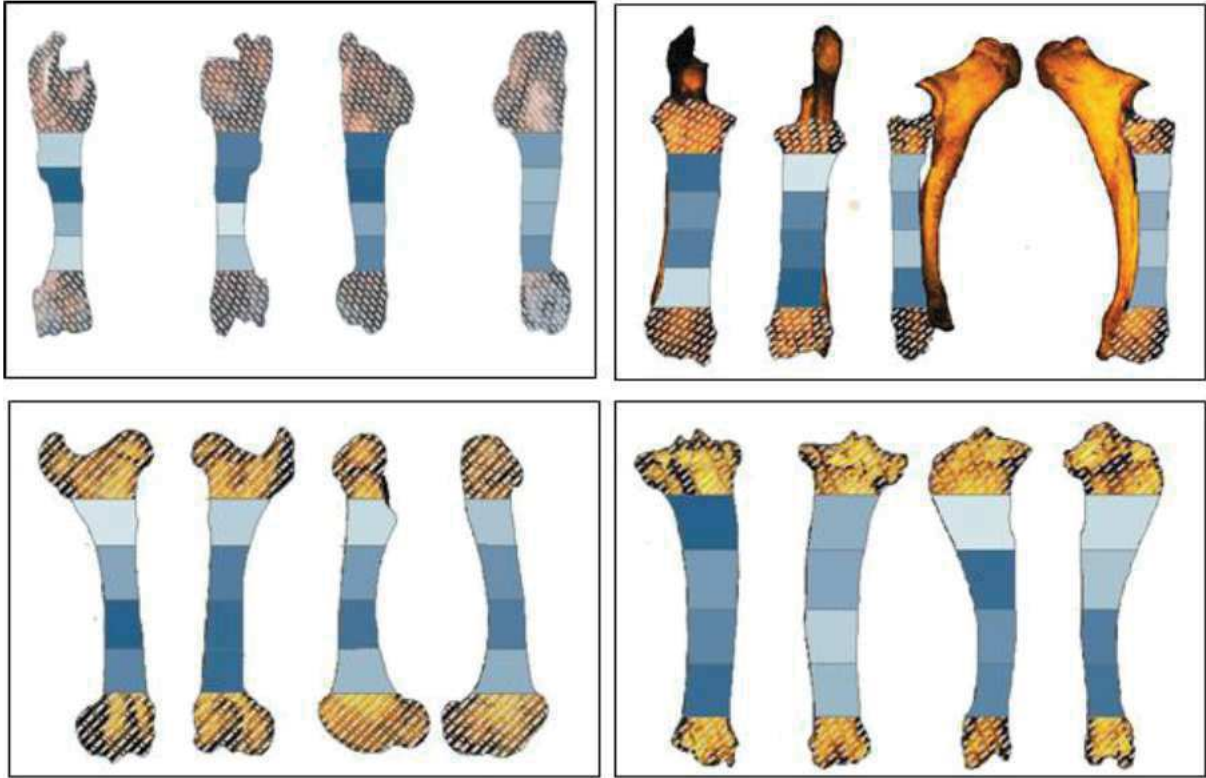
Dispersed 90-95%
confidence

Random

Clustered 90-95%
confidence

Clustered 99%
confidence

Supplementary data 2: Graduated maps of thickness measurements according to Barba et al (2005). Darker blue zones represent the thicker portions of the bone



Supplementary data 3: GIS percussion pattern analysis method

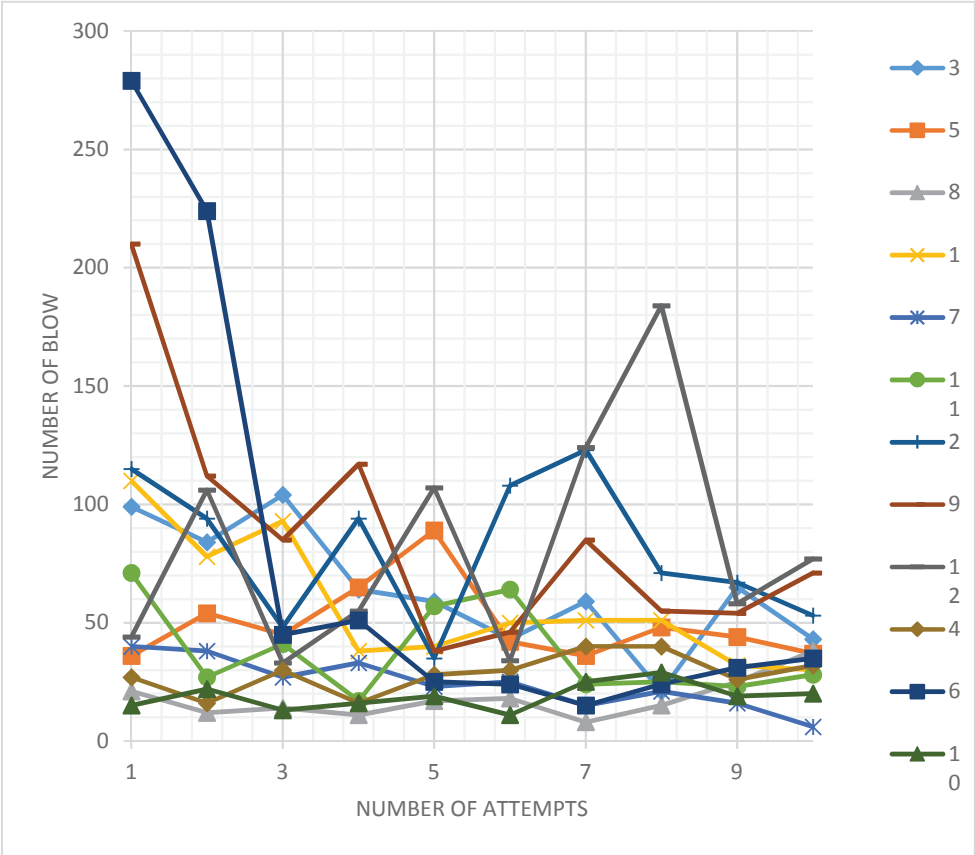
The GIS method for analysing percussion mark patterns is available on the site protocols.io Follow the link to access the step by step described method:

<https://www.protocols.io/private/34F6E71E3177B8E0F106B2A9369DD2C2>

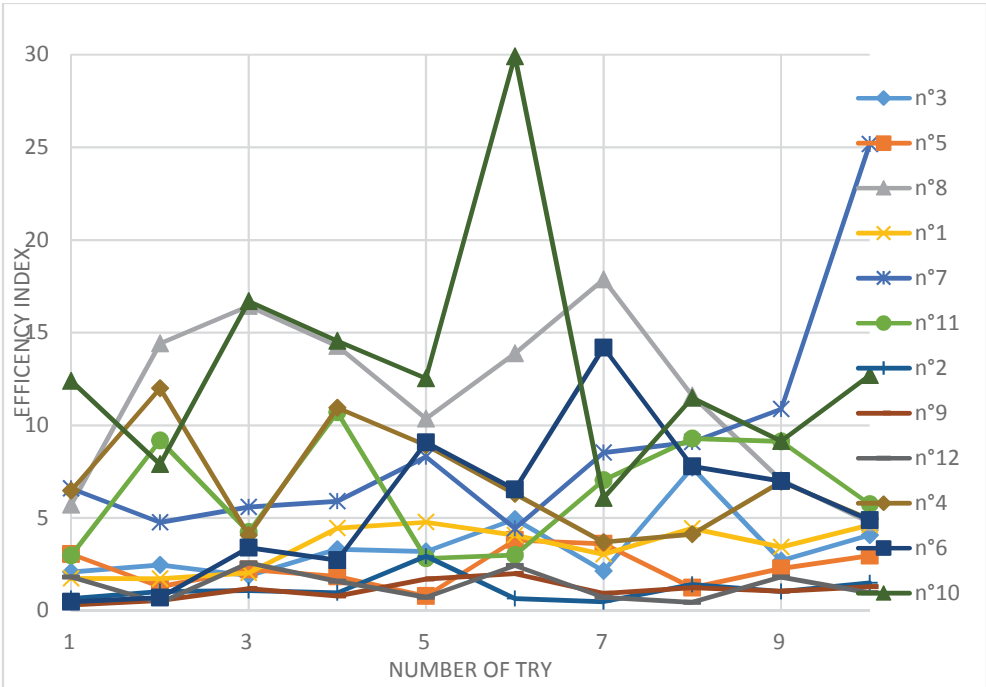
Annexes 2

Supplementary data

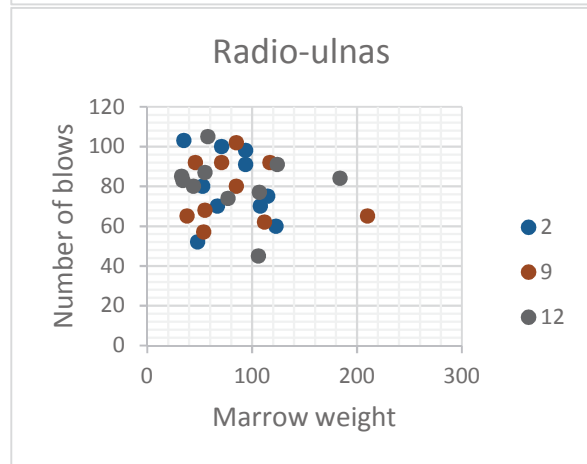
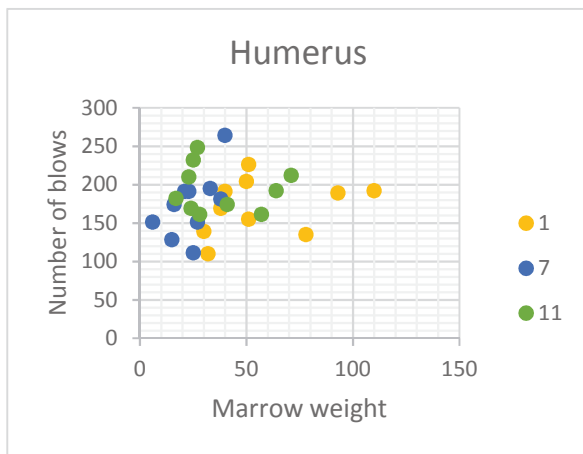
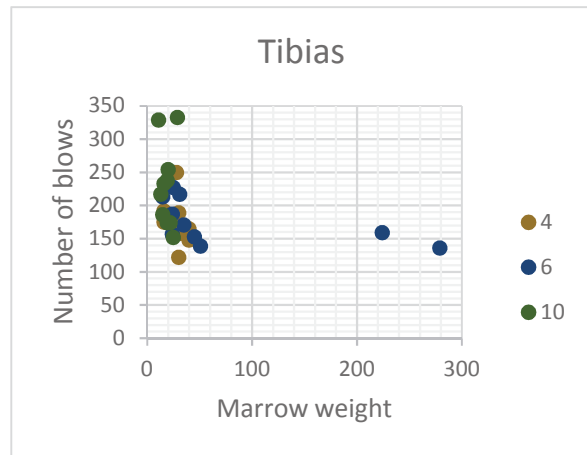
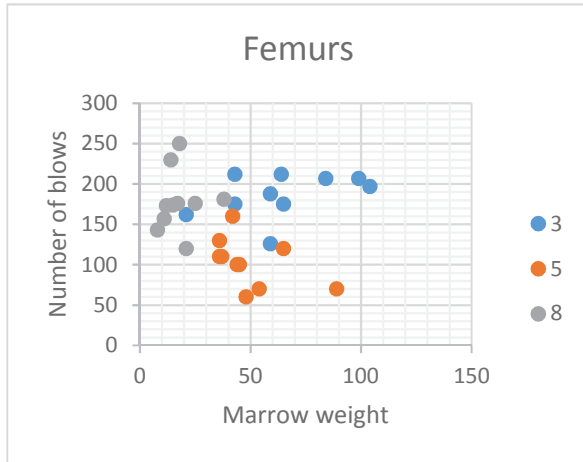
Supplementary data 1. The number of blows according to the number of try for each experimenter, with the linear regression.



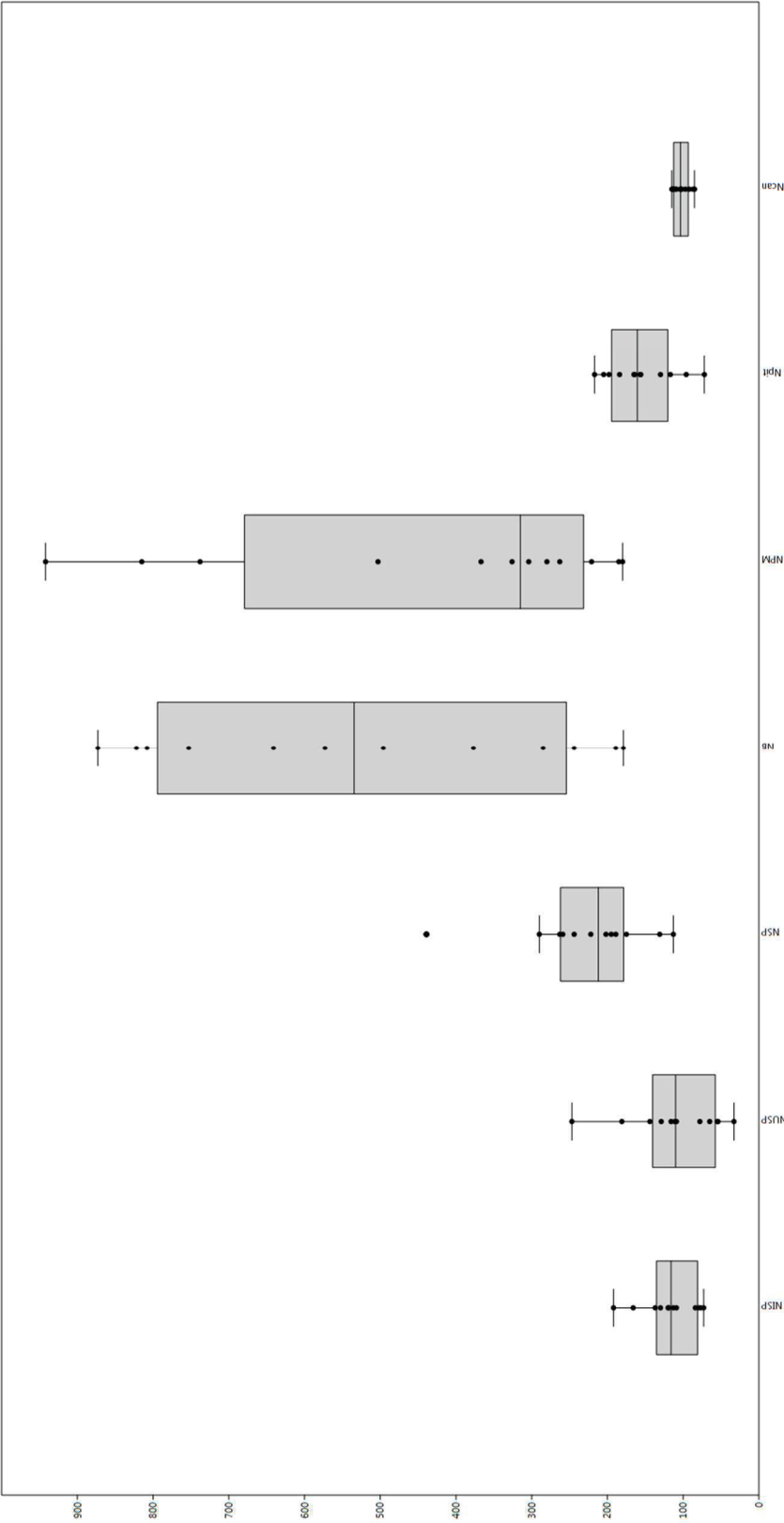
Supplementary data 2. Efficiency Index by individual during the experiment.



Supplementary data 3. The number of blows by the marrow weight (in gram) for each element.



Supplementary data 4. Box plots and jitter with outsider of NISP, NUSP, NSP, NB, NPM, Npit and NCNA for each serial.



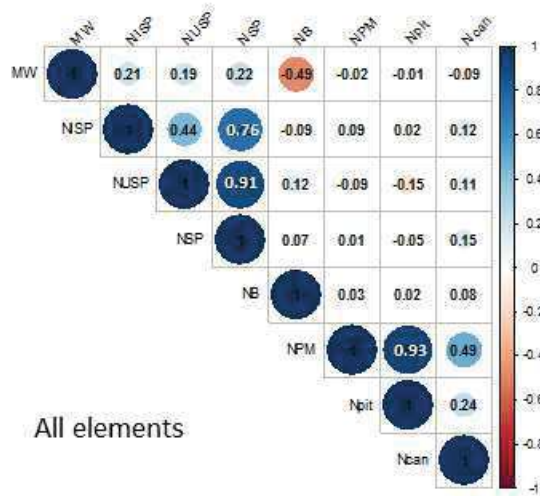
Supplementary data 5. The number of blows and the EFI, for each individual, regarding 50/50 the five first tries (T1) and the five last ones (T2), 3/-/3 the three first tries (T1) and the three last ones (T2).

Try groups	Bone	n°indiv	T1<T2									
			Number of blows		Efficiency Index		Number of blows		Efficiency Index			
			50/50	3/-/3	50/50	3/-/3	50/50	3/-/3	50/50	3/-/3		
T1	Femur	3	410	287	12.95	6.44942557	WRONG	WRONG	RIGHT	RIGHT	3	Femur
T1	Femur	5	289	135	9.21	6.57407407	WRONG	WRONG	RIGHT	WRONG	5	Femur
T1	Femur	8	75	47	61.19	36.5595238	RIGHT	RIGHT	WRONG	WRONG	8	Femur
T1	Humerus	1	359	281	14.73	5.50848184	WRONG	WRONG	RIGHT	RIGHT	1	Humerus
T1	Humerus	7	161	105	31.17	16.9557505	WRONG	WRONG	RIGHT	RIGHT	7	Humerus
T1	Humerus	11	213	139	29.95	16.4150031	WRONG	WRONG	RIGHT	RIGHT	11	Humerus
T1	Radio-Ulna	2	386	257	6.69	2.77806044	RIGHT	WRONG	WRONG	RIGHT	2	Radio-Ulna
T1	Radio-Ulna	9	562	407	4.56	2.06309524	WRONG	WRONG	RIGHT	RIGHT	9	Radio-Ulna
T1	Radio-Ulna	12	345	183	7.12	4.8184677	RIGHT	RIGHT	WRONG	WRONG	12	Radio-Ulna
T1	Tibia	4	117	73	42.41	22.5481482	RIGHT	RIGHT	WRONG	WRONG	4	Tibia
T1	Tibia	6	624	548	16.4	4.59727663	WRONG	WRONG	RIGHT	RIGHT	6	Tibia
T1	Tibia	10	85	50	64.09	37.0013986	RIGHT	RIGHT	RIGHT	WRONG	10	Tibia
T2	Femur	3	231	129	21.54	14.4763609	0.56341463	0.44947735	1.66332046	2.24459693		
T2	Femur	5	207	129	13.92	6.49570025	0.71626298	0.95555556	1.51140065	0.98807835		
T2	Femur	8	104	78	55.17	23.4031579	1.38666667	1.65957447	0.90161791	0.64013848		
T2	Humerus	1	214	113	19.62	12.5022059	0.59610028	0.40213523	1.33197556	2.26962823		
T2	Humerus	7	83	43	58.11	45.1369048	0.51552795	0.40952381	1.86429259	2.6620411		
T2	Humerus	11	164	76	34.2	24.1604348	0.76995305	0.54676259	1.14190317	1.47185076		
T2	Radio-Ulna	2	422	191	5.1	3.96266079	1.09326425	0.74319066	0.76233184	1.42641273		
T2	Radio-Ulna	9	311	180	6.53	3.58769384	0.55338078	0.44226044	1.43201754	1.73898605		
T2	Radio-Ulna	12	477	319	6.4	3.22790553	1.3826087	1.7431694	0.8988764	0.66990291		
T2	Tibia	4	168	98	26.02	16.0240385	1.43589744	1.34246575	0.61353454	0.71065874		
T2	Tibia	6	129	90	40.42	19.677381	0.20673077	0.16423358	2.46463415	4.28022557		
T2	Tibia	10	104	68	69.33	33.3406534	1.22352941	1.36	1.08176002	0.90106468		

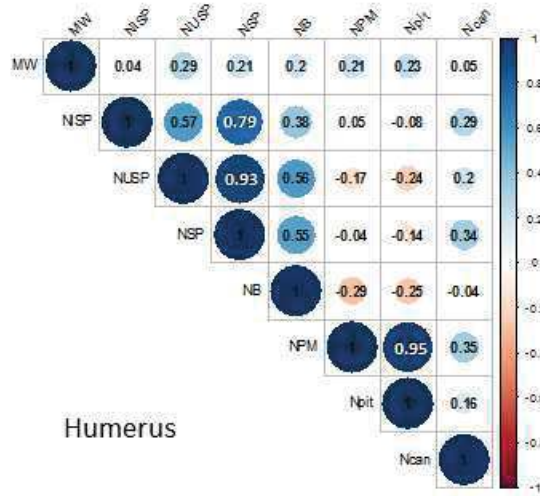
Supplementary data 6. Results of Wilcoxon signed rank test.

		All Element	Humerus	Radio-ulna	Tibia	Femur
Number of blows (50/50)	Degree of freedom	23	2	2	2	2
	t-test assumption	No	No	No	No	No
	Wilcoxon signed rank test	50	6	3	3	5
	P-value	0.1294	25	1	1	0.5
Number of blows (3/-/3)	Degree of freedom	23	2	2	2	2
	t-test assumption	No	No	No	No	No
	Wilcoxon signed rank test	61	6	4	3	4
	P-value	0.09229	0.0254	0.75	1	0.75
Efficiency Index (50/50)	Degree of freedom	23	2	2	2	2
	t-test assumption	No	No	No	No	No
	Wilcoxon signed rank test	21	0	3	2	2
	P-value	0.1763	0.25	1	0.75	0.75
Efficiency Index (3/-/3)	Degree of freedom	23	2	2	2	2
	t-test assumption	No	No	No	No	No
	Wilcoxon signed rank test	26	0	3	3	4
	P-value	0.3394	0.25	1	1	0.75

Supplementary data 7. Spearman's rank correlation coefficient results between the extracted marrow weight (MW), the NISP, the NUSP, the NSP, the number of blows (NB), the number of percussion marks (NPM), the number of pit (Npit) and the number of crushing marks and adhering flake and notch (NCNA)



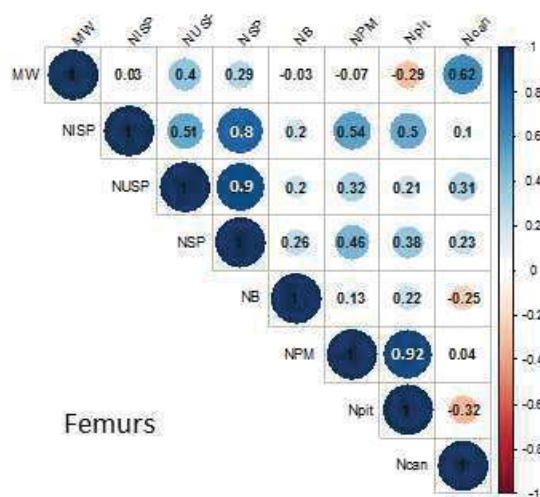
All elements



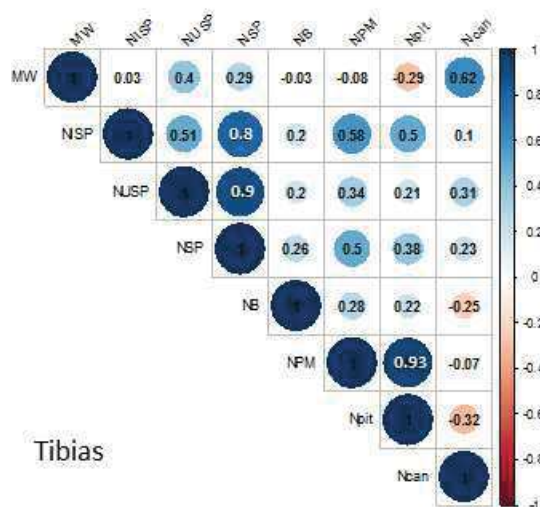
Humerus



Radio-ulnas



Femurs



Tibias

Annexes 3

Vettese, D., Daujeard, C., Blasco, R., Borel, A., Caceres, I., & Moncel, M. H. (2017). Neandertal long bone breakage process: standardized or random patterns? The example of Abri du Maras (Southeastern France, MIS 3). *Journal of Archaeological Science: Reports*, 13, 151-163.



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Neandertal long bone breakage process: Standardized or random patterns? The example of Abri du Maras (Southeastern France, MIS 3)

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ABSTRACT

The identification of social learning processes and knowledge transmission mechanisms in the archaeological record is a matter currently explored on lithic record but not very often on faunal assemblages. As soon as the Middle Palaeolithic, the uniformity and orientation of cut marks or patterns of bone breakage may represent very useful tools to highlight butchery traditions. Following this line of research, we have tried to identify standardized actions on bones in the process of marrow recovering and therefore butchery cultural learning within Neandertal groups at Abri du Maras (MIS 3, Southeastern France). The detection of culturally-induced patterns involves the discrimination of those generated intuitively, which depend on conditioning factors such as bone density or skeletal morphology. To tackle this issue, we have used a zooarchaeological approach focused on the morphology and location of damage caused during the bone breakage process (percussion marks and scraping marks). We also compare our data with previously published results both at a zooarchaeological and experimental level. Our work indicates that the bone remains from layer 4.1 at Abri du Maras do not reveal standardized patterns of long bone breakage in terms of distribution of impact notches along long bone shafts and then imply two hypotheses: 1) the presence of several groups with various butchery practices during the sedimentary formation and the marked palimpsest character of this layer or 2) the presence of individuals within one single group which do not share similar butchery know-how.

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1. Introduction

From 400 ky onwards, many sites in Europe and the Near East attest to the improvement of hunting strategies and carcass processing. The discovery of spears at the sites of Schöningen (Germany) and Clacton-on-Sea (England) shows the range of innovations already in use as early as the Lower Palaeolithic (Thieme, 1997; Oakley et al., 1977; Schoch et al., 2015). Within human groups, meat consumption remains indicate the generalization of new collective practices: selective transport and processing of selected skeletal portions at the camp; systematization of butchering practices (task specialization) and meat sharing (e.g., Huguet et al., 2001; de Lumley et al., 2004; Moigne et al., 2005; Stiner et al., 2009, 2011; Sam and Moigne, 2011; Daujeard and Moncel, 2010; Blasco et al., 2014b).

Analyses of the lithic material result in the identification of technical traditions and are assumed to be the characteristic markers of a group and of an inter-generational transmission of knowledge from the Early

Palaeolithic phases onwards (e.g., Moncel et al., 2012, 2014; Stapert, 2007; Turq et al., 2013; Faivre et al., 2014). On the other hand, the assessment of specific group traditions based on butchering techniques is a much lesser developed approach. Studies of butchery marks generally consist in identifying butchery activities or in differentiating them from marks left by other taphonomic agents (carnivores, trampling, etc.) (Blumenschine and Selvaggio, 1991; Pickering and Egeland, 2006; Dominguez-Rodrigo et al., 2009; Galan et al., 2009). Our knowledge of the social organization of human groups based on the fossil bone record is mainly focused on the hunting techniques. For example, mass kill sites of large ungulates are associated with organized hunts, requiring the presence of a group of several individuals (Gaudzinski, 1995; Rendu, 2010; Delagnes and Rendu, 2011).

Butchering techniques, in the same way as core technologies or tool retouches, provide an innovative avenue of research for attempting to define the specific traditions of a human group through a possible standardization of their butchering practices. This is the hypothesis advanced by Blasco et al. (2013), based on a comparison of the notch distribution patterns at two Spanish Middle Pleistocene sites: Bolomor Cave – levels XVII (sublevels XVIIa and XVIIc), XI and IV (MIS 9–5e)

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and Gran Dolina, Atapuerca – sublevel TD10-1 (upper part, ca. MIS 9). Bolomor IV showed a strong bone breakage pattern, which is far from the intuitive standardization depending on factors such as the bone density and/or skeletal morphology, as observed experimentally. These patterns therefore were interpreted as culturally-induced. On the contrary, the rest of levels of Bolomor (e.g., XVIIa) and TD10-1 (upper part) of Gran Dolina show no preferential areas to break open the limb bones; circumstance that was interpreted as the result of the presence of several groups with different ways of processing the carcasses (palimpsest composed of several human occupations). On this basis, we try here to assess the existence of cultural traditions on another long bone assemblage accumulated by Neandertals in Abri du Maras (layer 4-1, MIS 3, France). This site presents an advantage in that quasi-absence of carnivore intervention is recorded on the bones. In order to carry out this study, we analysed the bone assemblage by using a zooarchaeological approach focused on percussion marks. We then compared our results with the experimental and the archaeological data of [Blasco et al. \(2013\)](#).

2. Chronological, environmental and archaeological frameworks

Abri du Maras (South-East France, Saint-Martin d'Ardèche) is a vast rock-shelter located at the exit of the Ardèche gorges, in a dry valley. It is about 1 km from the present day river bed, on its left bank, and 7 km from the Rhône Valley River mouth ([Fig. 1](#)). The site is at an altitude of 170 m. Today, the southeast facing shelter is 12 m long, 3 m wide, with an internal height of 2 m ([Combiér, 1967](#)).

Abri du Maras was excavated in the 1950s–1960s by R. Gilles and J. Combiér. These first excavations unearthed a stratigraphic sequence made up of eight archaeological levels ([Combiér, 1967](#)). In 2006, a test pit was opened to assess the available data from the site and led to the reopening of excavations in 2006 ([Moncel et al., 2010](#)). Since then, the site is excavated each year as part of a programmed project directed by M.-H. Moncel.

These recent excavations have mainly focused on level 4, which corresponds to a heterogeneous silty deposit attributed to the beginning of the last glaciation (MIS 3) ([Moncel and Michel, 2000](#); [Richard et al.,](#)

[2015](#)). The coarse fraction of the sedimentary deposits is due to the dismantling of the wall as a result of cryoclastic disturbances. It is divided into two main occupation layers (4-1 and 4-2), separated by an almost sterile loessic level. Layer 4-1, the subject of the present study, was excavated over >40 m². The thickness of layer 4-1 is on average of 30 cm and the concentration for the archaeological remains is of 439 remains/m³ and specifically for the faunal remains of 228/m³. Thirteen ashy lenses have been discovered in situ at various depths and the use-wear data point to a wide variety of on-site domestic activities, including activities other than butchery ([Hardy et al., 2013](#)).

The occupation phase of layer 4-1 indicates specialized autumnal reindeer hunts and an intense on-site butchering activity. The large fauna points to a cold and dry climate and an open steppic landscape favourable to large gregarious ungulates, with, in decreasing order of importance; the reindeer (*Rangifer tarandus*), the horse (*Equus ferus cf. germanicus*), the megaceros (*Megaloceros giganteus*), the red deer (*Cervus elaphus*), the bison (*Bison priscus*) and the ibex (*Capra ibex*). Several Lagomorph remains have also been identified. No carnivore remains have been recorded. The taphonomy of the fauna revealed almost exclusively anthropogenic accumulation processes. There are few carnivore marks (<1% of the total legible remains) and cut marks are very frequent (>25%). Ungulates are represented by all age classes. The skeletal profiles for the reindeer and the horse indicate the existence of initial processing at the kill sites and a transport strategy of skeletal parts ([Daujeard and Moncel, 2010](#)).

The lithic industry from layer 4-1 is a Middle Palaeolithic industry with predominantly Levallois core technology ([Combiér, 1967](#); [Moncel et al., 1994](#); [Moncel, 2005](#); [Moncel et al., 2015](#)). The first studies conducted by J. Combiér (1967) and R. Gilles in the upper layers of the sequence revealed the presence of a Mousterian with blade-type Levallois debitage. This preferential use of Levallois debitage was once again observed during recent excavations in the lower part of the infilling. The abundance of the series in layer 4-1 allows for the description of both complete and partial operative sequences (debitage on imported large flakes). The largest blades, points and flakes were knapped before being brought to the site, where they were then used on-site. They point to an anticipation of tool kit requirements ([Moncel](#)

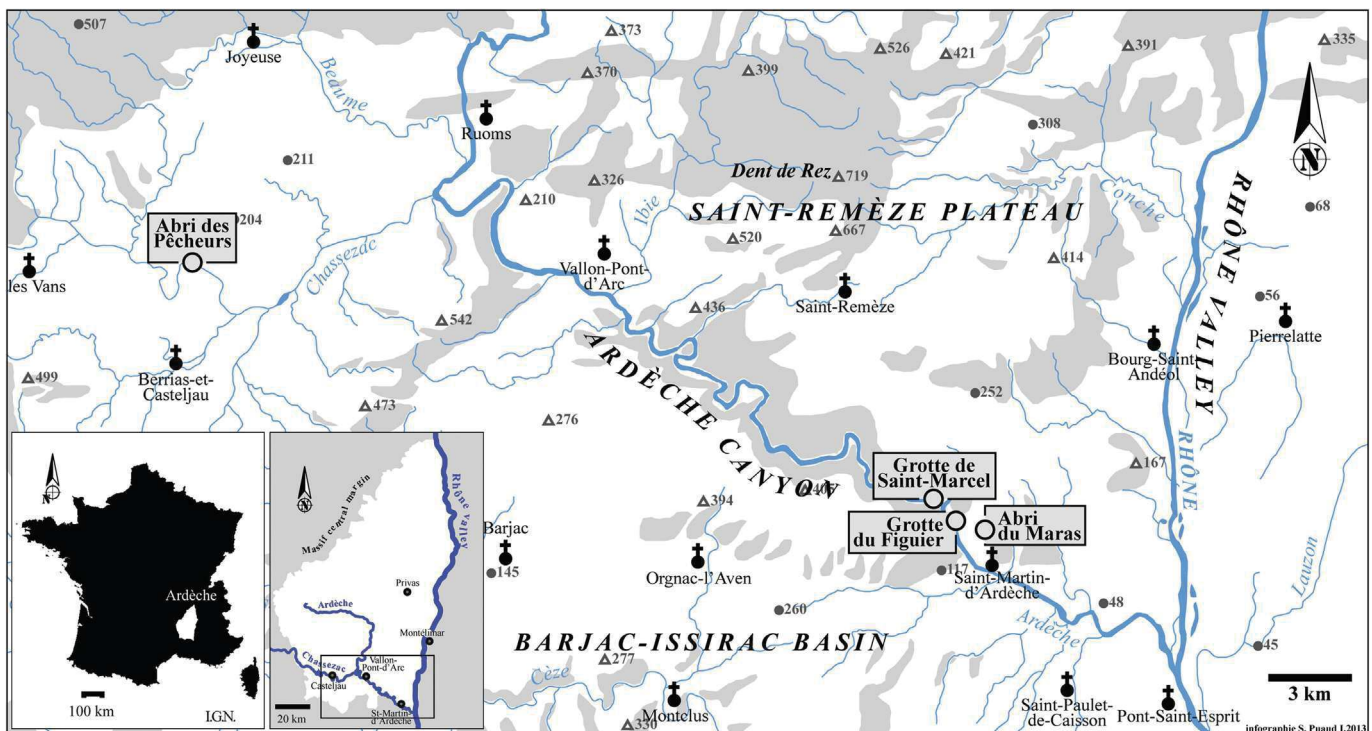


Fig. 1. Location of Maras rock shelter south-eastern France. View of the topographical position of the site in a small valley near the Ardèche River (in [Moncel et al. 2014](#)).

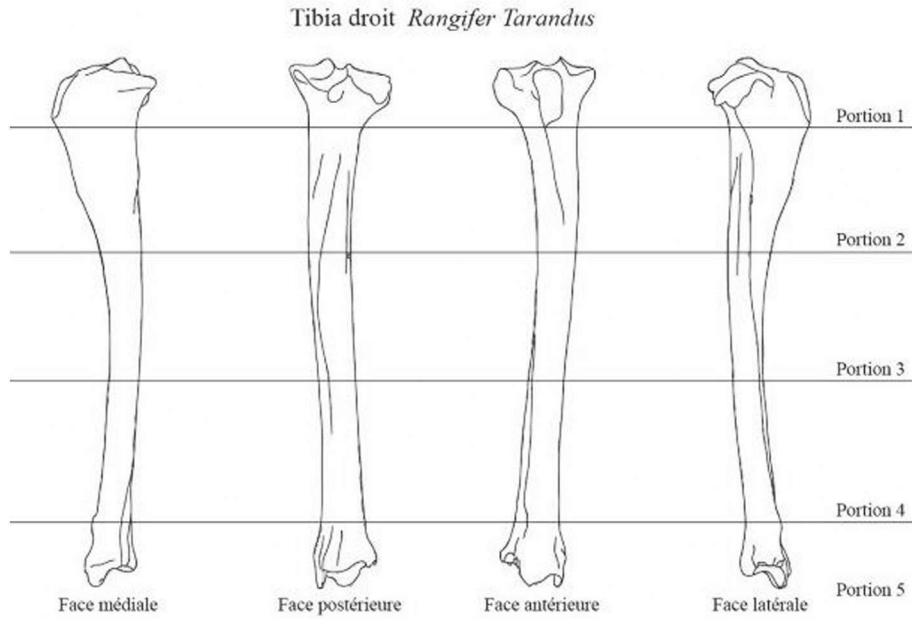


Fig. 2. Example of the nomenclature used in the description of the bone portions and surfaces. Portion 1 (P1): proximal articular end; Portion 2: proximal diaphysis; Portion 3: medial diaphysis; Portion 4: distal diaphysis; Portion 5: distal articular end (after the drawing by Castel (2010), reference J. C. Castel (Geneva Museum) - © 2013 archéozoo.org).

et al., 2014). The raw materials of these pieces come from sectors located <20 km to the north and south of the site, on the right bank of the Rhône (Moncel et al., 2014). The activities carried out on-site required additional tools to these scant large artefacts. The importation of previously knapped products, as the presence of partial reduction sequences, suggests that the rock shelter was occupied for short-term periods (Moncel et al., 2014).

3. Material and methods

3.1. Sample

The studied material comes from layer 4-1 of Abri du Maras, excavated from 2006 to 2013. Our analysis only concerned the long bone remains from middle and large-sized ungulates. In layer 4-1 the

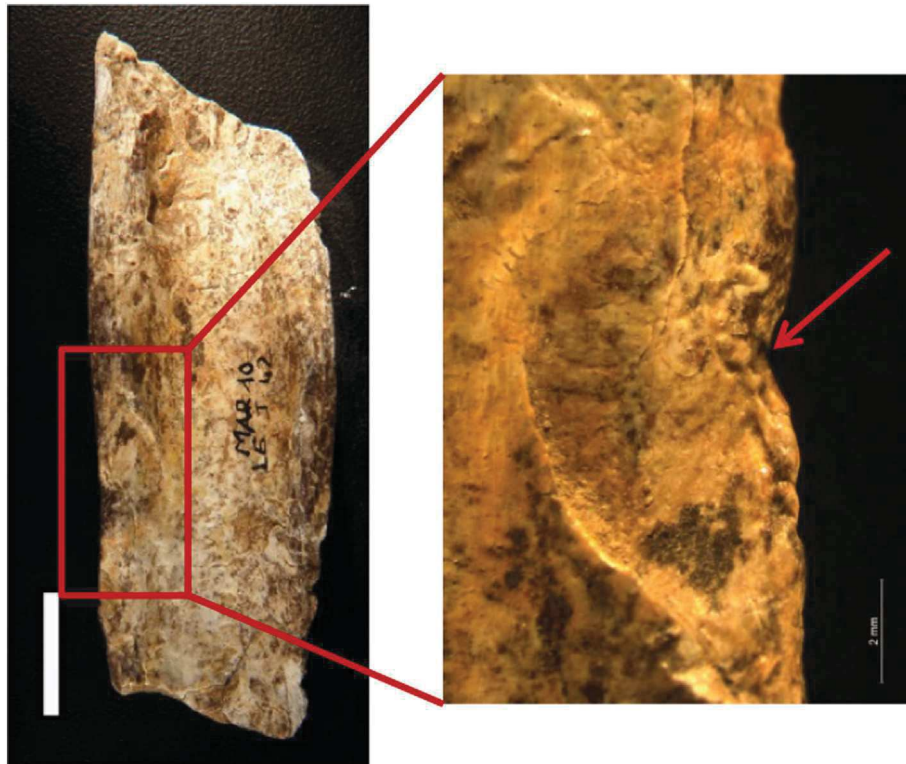


Fig. 3. Percussion marks of a reindeer metacarpal (scale 1 cm and 2 mm). We can observe a micro-notch on the magnified picture (red arrow). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Number of remains for the archaeological studied sample (NISPt and MNI).

Species	NISPt	%NISPt	MNI	%MNI	MNIjuv
<i>Rangifer tarandus</i>	680	93.2%	19	68%	3
<i>Equus caballus</i> cf. <i>germanicus</i>	21	2.9%	2	7%	0
<i>Megaloceros giganteus</i>	15	2.1%	2	7%	0
<i>Bison</i> sp.	6	0.8%	1	4%	0
<i>Cervus elaphus</i>	4	0.5%	1	4%	0
<i>Rangifer/Capra</i>	2	0.3%	1	4%	0
<i>Cervus/Rangifer</i>	1	0.1%	1	4%	0
<i>Megaloceros/Cervus</i>	1	0.1%	1	4%	0
Total	730	100%	28	100%	3
MUNG IND	59	76%			
LUNG IND	19	24%			
Total IND	78	100%			
Total	808				

proportion of long bone fragments among the total Number of anatomically Identified Specimens (NISPa) is very important (60.16%; N = 808/1343). Thus, 808 long bone remains were studied, 730 of which were taxonomically identified. Despite their abundance in the sample, we did not include the indeterminate bone splinters in our analysis. This choice is justified by the necessity to avail of detailed data concerning the localization of impact marks within anatomical elements.

3.2. Taphonomy

We used the following count indexes (Binford, 1981; Lyman, 1994; Brugal et al. 1994): the total Number of Remains (NR); the Number of taxonomically Identified Specimen (NISPt); the Number of anatomically Identified Specimen (NISPa); the Minimum Number of Elements (MNE); the Minimum Number of Individuals (MNI) and the Minimum Animal Unit (MAU). We recorded anatomical, taxonomic and surface modification data for all recorded and identified specimens.

The three dimensions (length, width, thickness) were measured for each element. The shaft fragments were differentiated by size and circumference classes (cf. Villa and Mahieu, 1991 $0 < L1 < 0.25 \leq L2 < 0.5 \leq L3 < 0.75 \leq L4 \leq 1$; $0 < C1 < 0.5 \leq C2 < 1$; $C3 = 1$). In order to take into account the taxonomically indeterminate fragments, we established two main size categories adapted to the studied ungulates:

- Medium-sized ungulates (MUNG) with a weight between 100 and 300 kg (reindeer and red deer);
- Large-sized ungulates (LUNG) with a weight between 300 and 1000 kg (horse, bison and megaceros).

Table 2
Number of anatomically Identified Specimen (NISPa), Left (L) and Right (R) sides, Number of Indeterminate Remains (ind), Number of Remains belonging to juveniles (juv), Minimum Number of Element (MNE), Minimum Animal Unit (MAU), maximal length (Max), minimal length (Min) and mean size of long bones (Mean).

	NISPa	%NISPa	L	R	ind	juv	MNE	MAU	% MAU	Max (mm)	Min (mm)	Mean (mm)
MUNG (Total)	742	100%	165	190	387	11	225	112.5		193	16	57.4
Humerus	97	13%	32	40	25	0	34	17	55%	123	23	54.9
Radius	123	17%	34	32	57	1	41	20.5	66%	193	22	59.6
Metacarpal	58	8%	13	14	31	2	19	9.5	31%	181	16	60.3
Femur	45	6%	8	12	25	0	17	8.5	27%	110	28	61.4
Tibia	184	25%	53	58	73	3	41	20.5	66%	166	16	63.5
Metatarsal	167	23%	24	33	110	2	62	31	100%	150	16	56.9
Metapodial	68	9%	1	1	66	3	11	5.5	18%	101	16.6	45.2
LUNG (Total)	66	100%	33	13	20	0	16	8		226	35	103.3
Humerus	5	8%	1	2	2	0	2	1	40%	78	55	70.6
Radius	8	12%	4	1	3	0	2	1	40%	156	73	108.3
Metacarpal	2	3%	1	0	1	0	0	0	0%	226	62	144
Femur	9	14%	3	4	2	0	2	1	40%	142	38	102.8
Tibia	28	42%	11	6	11	0	5	2.5	100%	161	49	84
Metatarsal	14	21%	13	0	1	0	5	2.5	100%	219	35	110.4
Metapodial	0	0%	0	0	0	0	0	0				
Total	808											

The long bones were studied using a classical taphonomic and zooarchaeological approach. All the bone surfaces were observed with naked eyes under a low-angled light and a stereomicroscope (Leica S8 APO $\times 10$ –80) when necessary. For each faunal remain, we systematically recorded the different taphonomic alterations (meteorological, geological and biological) using the criteria established by Behrensmeyer (1978), Binford (1981), Lyman (1994) and Blumenschine et al. (1996) (among others). The illegible remains were not included in the percentages.

Burnt damages were recorded according to the different colour stages used by Stiner et al. (1995) but simplified into three main stages:

- stage 1: lightly burnt (colour: mainly brown);
- stage 2: carbonized (colour: mainly black);
- stage 3: calcined (colour: mainly white).

The works of Binford (1981), Shipman and Rose (1984), Behrensmeyer et al. (1986), Olsen and Shipman (1988) and Dominguez-Rodrigo et al. (2009), enabled us to distinguish butchery striations from trampling ones. Adapted from the definition of Lyman (2008), we recorded two types of striations: incisions and scraping marks. Chopping marks were recorded as a type of percussion marks. Using the localization and morphology of these marks on the skeleton, it was possible to interpret the butchery activity (Binford, 1981; Valensi, 1991; Nilssen, 2000; Pobiner et al., 2008). Apart from scraping marks, following on Blasco et al. (2013), butchering striations were not taken into account in this study of standardization butchering gestures. Indeed, the cut marks location is linked to the morphology and size of the animal. Besides that, the frequency of cut marks may also be related to the dexterity of the butcher. And finally, their variability, both in their occurrence and morphology, depends to the raw material, the type of tool and the type of action developed (e.g. Domínguez-Rodrigo and Yravedra, 2009; Val et al. 2017).

3.3. Fracturation

Post-depositional and fresh bone fractures were identified based on the fracture features (Villa and Mahieu, 1991). Specific analyses were carried out concerning long bone marrow processing (percussion marks and scraping marks). Yellow marrow from long bones can be extracted using two main methods: the bone can be struck on an anvil with a hammer with or without retouch (whereby the bone has a passive role), or the bone can be fractured directly against an anvil or a wall by “batting” (where the bone has an active role) (Blasco et al.,

Table 3
Number of epiphysis and diaphysis long bone portions and ratios of epiphysis on diaphysis (E/D).

	Epiphysis	Diaphysis	E/D
MUNG	162	888	0.18
LUNG	21	90	0.23
Total	183	978	0.19

2014a; Rovira and Caceres, 2013). In order to identify the preferentially impacted zones, we localized each fragment according to its long bone portion (Fig. 2). The recorded percussion marks are (Blumenschine and Selvagio, 1988, 1991; Capaldo and Blumenschine, 1994; White, 1992; Blasco et al., 2013):

- medullary or cortical percussion notches (negative flake scars);
- impact flakes (positive flake scars);
- percussion pits;
- adhering flakes;
- peeling;
- micro-notches (very small notch present in the centre of the percussion notch) (Fig. 3).

The depth of the notches was taken into consideration using three different categories: d1 (<1/2 initial cortical height), d2 (>1/2 and <1 initial cortical height) and d3 (= 1, totality of the cortical height). Percussion on an anvil with a non-retouched pebble sometimes produces counterblows (Rovira and Caceres, 2013). We also registered opposite notches resulting from counterblows (double opposing notches) (Galan et al., 2009). These double notches are observed on the remains as two notches located in the same portion but on exact opposite sides.

3.4. Experimental data

To distinguish intuitive from counter-intuitive way to break long bones among archaeological data, we use comparative experimental data from of Blasco et al. (2013). Indeed, one of the objectives of the experimentations of Blasco and colleagues was to decipher intuitive behaviours during marrow processing made by non-trained experimenters. These latter used two different methods to hit long bones of adult cows (humeri, radio-ulnas, femurs and tibias): by batting (six experimenters) and by hammerstone on anvil (eight individuals). We compare the data obtained for each method with the ones from our archaeological data and those from Bolomor and Gran Dolina (Blasco et al., 2013, Supplementary data).

Table 4
Main bone surface alterations (NR and τ).

	Root etchings				Illegibility		Total NR				
	v0	v1	v2	v3	NR	τ					
MUNG	29	3.9%	246	33.2%	270	36.4%	197	26.5%	180	24.3%	742
LUNG	4	6.1%	16	24.2%	20	30.3%	26	39.4%	25	37.9%	66
Total	33	4.1%	262	32.4%	290	35.9%	223	27.6%	205	25.4%	808

Table 5
Frost, green, dry and indeterminate long bone breakage (NR and τ).

	Gelifraction	Green	Dry	Ind	Total				
MUNG	16	2.2%	682	91.9%	221	29.8%	91	12.3%	742
LUNG	2	3.0%	59	89.4%	21	31.8%	3	0.4%	66
Total	18	2.2%	741	91.7%	242	30.0%	94	11.6%	808

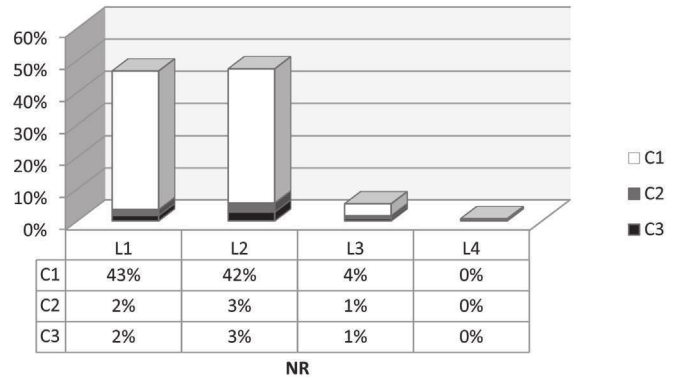


Fig. 4. Diagram showing relative frequencies of shaft length and circumference for MUNG (medium-sized ungulates) long bone elements.

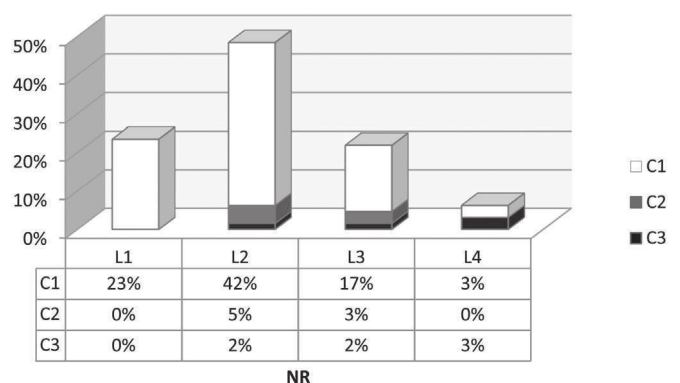


Fig. 5. Diagram showing relative frequencies of shaft length and circumference for LUNG (large-sized ungulates) bone elements.

3.5. Data analysis

Spearman's test was used to evaluate the correlation between the %MAU and long bone density indexes and thus the existence of a differential preservation within the archaeological faunal assemblage. We also employed this bivariate test to cross the %MAU and the medullary cavity volume of reindeer long bones (Jones and Metcalfe, 1988; Metcalfe and Jones, 1988) to explore the human carcass transport strategies. To evaluate the influence of bone features (density and morphology) on the location of percussion impacts, we statistically crossed the frequencies of percussion marks by portion with long bone density indexes (Lyman, 1994; Lam et al., 1999). Those correlations were only tested for medium-sized ungulates and shaft portions. For the few large sized-ungulate remains, we used descriptive statistic because of the scarcity of remains. These coefficients were calculated and their statistical significance tested using the software PAST (Hammer et al., 2001). We used an alpha of 0.05 for all the tests performed.

As Cochran's rules was not respected, we used Fisher exact tests with R (R core team, 2016) to test the independence between the frequency and location of impacts on both middle- and large-sized ungulates shafts individually and also for both of them, additionally. Correspondence analysis (CA) was used in order to investigate the potential

Table 6
Number of remains with burnt damages (stages 1 to 3).

	Stage 1	Stage 2	stage 3	NRT
MUNG	4	3	2	9
LUNG	0	0	1	1
Total	4	3	3	10

Table 7
NR (Number of Remains), PM (percussion marks) (NR and τ).

	NR	PM	
		NR	%
<i>Rangifer tarandus</i>	680	168	24.7%
<i>Equus caballus</i>	21	6	28.6%
<i>Megaloceros giganteus</i>	15	5	33.3%
<i>Bison</i> sp.	6	1	16.7%
<i>Cervus elaphus</i>	4	1	25.0%
IND	87	28	32.2%
HUM	102	37	33.3%
RAU	131	26	18.3%
METC	60	15	21.7%
FEM	54	19	35.2%
TIB	212	84	36.8%
METT	183	37	20.2%
METP	66	2	3.0%
Total	808	220	25.6%

existence of counter-intuitive butchery patterns. For the CA, we choose to take into account only medium-sized ungulates for Abri du Maras because of its reindeer-dominant faunal spectrum. The sample of layer 4-1 of Abri du Maras was compared with archaeological samples of Bolomor (IV, XVIIa, XVIIc) and Gran Dolina (TD-10-1 [upper part]) and with two experimental series (long bone breakage process by batting and with hammerstone on an anvil: data from Blasco et al., 2013). We discarded Bolomor level XI because of low quantity of material recovered during

the excavation of this sedimentary unit. Following Blasco and colleagues, we studied only humeri, radio-ulnas, femurs and tibias. Metapodials were discarded because of their absence in the experimental samples. CA were computed with the library Factomin'R (Lê et al., 2008).

4. Results

4.1. Zooarchaeological and taphonomic features of the long bone sample

Among the studied sample, reindeer largely dominate the spectrum, reaching >90% of the NISP. Horse, megaceros, red deer and bison are following. Most of the individuals are adults, and only three reindeer remains belong to juveniles (Table 1). Among indeterminate remains, the medium-sized ungulates are largely dominant.

The best-represented long bones for medium-sized ungulates are the metatarsals (100% of the MAU), followed in order of abundance by the humeri, radio-ulnas, tibias, metacarpals and femurs (Table 2). Concerning possible strategies in the selection of the long bones, we correlate the %MAU of medium-sized ungulates with the volume of the medullary cavity. The %MAU and the volume of the medullary cavity are not significantly correlated ($\rho = 0.257$; $df = 5$; $t = 0.848$, $p > 0.05$).

Long bones are highly fragmented. We count only four complete bones: two left metacarpals and one right metatarsal of reindeer and a right metacarpal III of horse. Shaft bone portions are far more numerous than articular portions (Table 3). The %MAU and the bone density

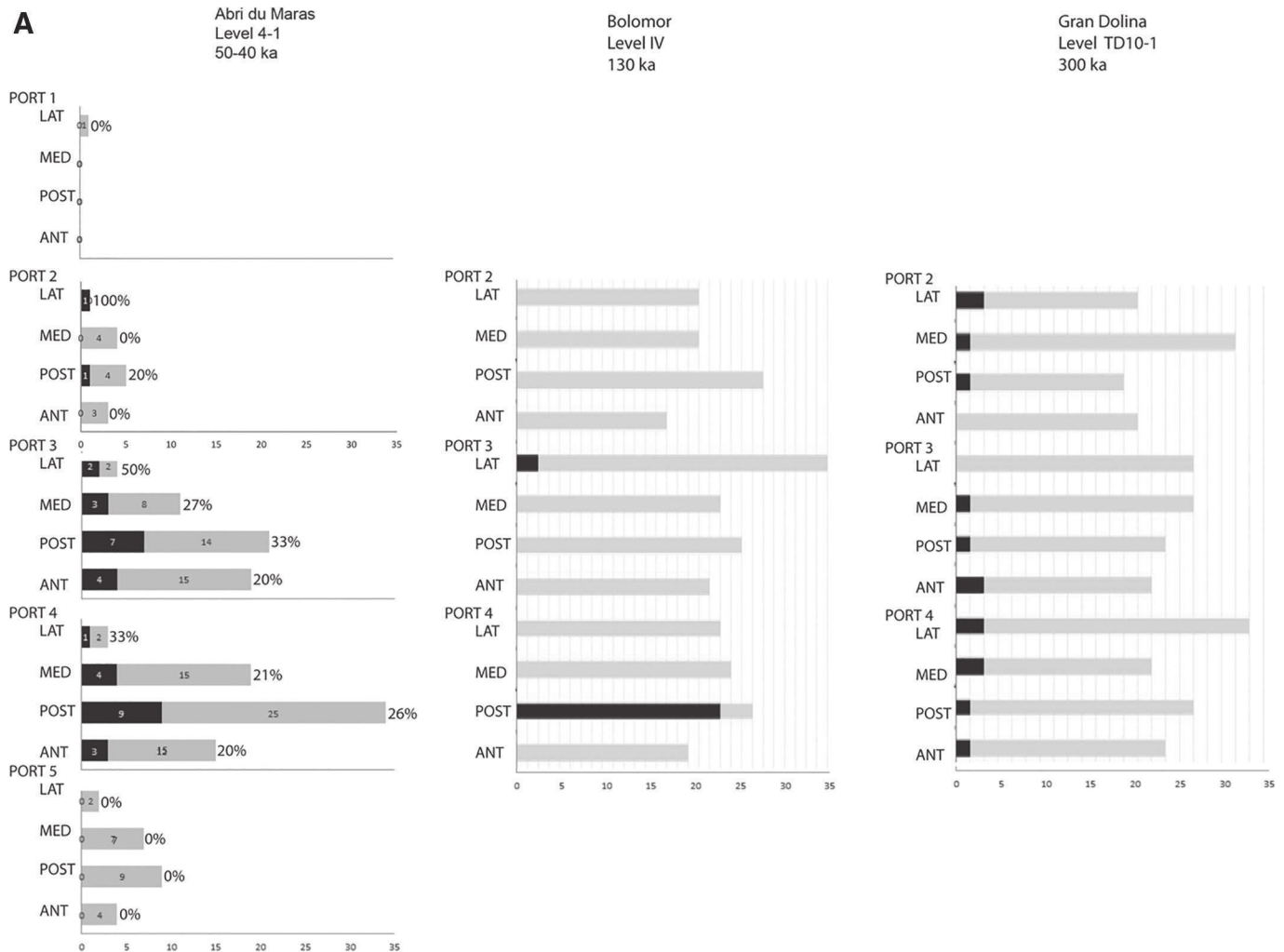


Fig. 6. Relationship between the total of recovered bone portions and bone portions with impact notches from Abri du Maras level 4-1 (MUNG), Bolomor level IV and Gran Dolina level TD 10-1 (all class-sized) faunal assemblages by skeletal elements belonging to appendicular skeleton of ungulates.

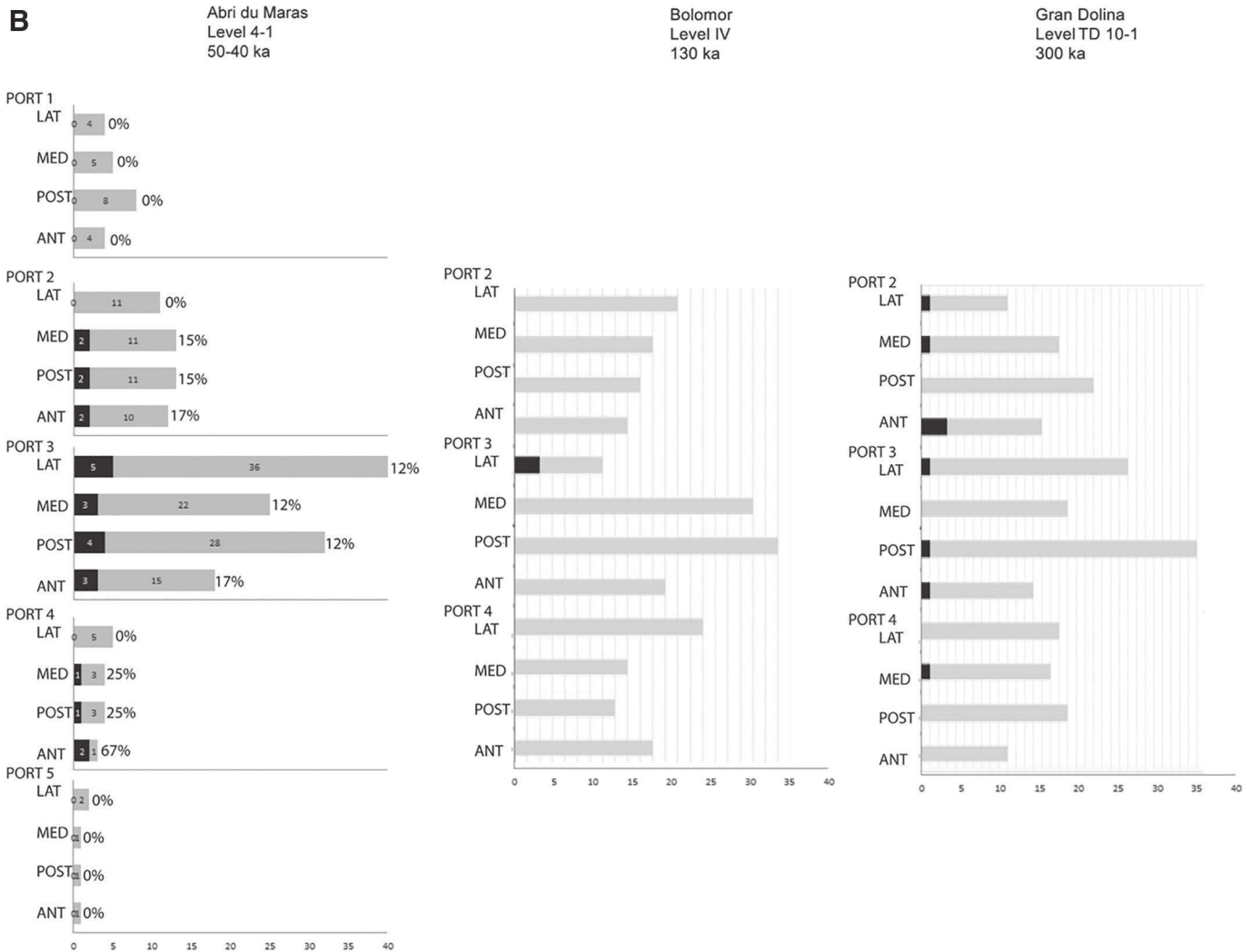


Fig. 6 (continued).

indexes of medium-sized ungulates are positively and significantly correlated ($\rho = 0.865$; $df = 29$; $t = 3.593$, $p < 0.05$) (S1). Thus, the low rate of epiphysis portions compared to diaphysis could be explained by the differential preservation. They may also have been used as fuel or crushed to extract bone grease of spongy parts (Daujeard, 2008; Daujeard and Moncel, 2010).

About one quarter of the remains have illegible surfaces (Table 4). Root etchings have caused the dissolution of most of the bone surfaces. Percussion notch analyses were not directly impacted, but that is not the case for peeling and percussion pits on bone surfaces that may have been unnoticed. Only two remains show carnivore marks (pits) and there are no digested elements, nor carnivore remains.

Fragmentation occurred mostly at the time of the human occupations. Indeed, >90% of the remains bear one or several green bone fractures, according to the criteria established by Villa and Mahieu (1991) (Table 5). Fractures profiles are mainly curved/V-shaped along with oblique angles and smooth edges. All types of long bones were broken for both middle and large-sized ungulates. The vast majority (>80%) have been reduced to a C1 circumference and have a L1/L2 length (Figs. 4 and 5). Post-depositional breakage damaged one third of the total remains. Secondary frost action and sediment compaction had only a low effect on bone fragmentation.

Among our sample, we observe only ten burnt bones, nine for medium-sized ungulates and one for large-sized. This last one is calcined, like

two of the medium-sized ungulate remains. Among these latter, three other are carbonized and four have just been lightly burnt (brown colours) (Table 6).

Cut marks are documented on 224 bones (37%; S2). Incisions and scraping marks have been identified. Cut marks analysis enabled us to identify disarticulating, defleshing, tendon removals and skinning activities. Scraping marks represent 15% of the cut marks and they are present on 6% of the long bone elements for the medium-sized ungulates and 13% of those of large-sized (illegible remains discarded). For this class of ungulate, only tibia and metatarsal bear scraping marks. For the medium-sized ungulates, all the long bones have scraping marks. For radio-ulnas and metacarpals, nearly 30% of the cut-marks are scraping marks. For humeri this rate decreases to <20% and we have 12% for tibias and metatarsals. Scraping marks on femurs are few and represent only 6% of the total cut-marks.

Nearly 90% of the scraping marks present on the metatarsals are present all along the anterior and posterior grooves. For the metacarpals, they are all located on the anterior surface of the bone. For the other long bones, they are unequally distributed over the shaft.

4.2. Long bone breakage process

We identified 220 long bone elements with diagnostic marks of intentional anthropogenic breakage, which represents one quarter of



Fig. 6 (continued).

them. These marks are mainly percussion notches or impact flakes (S3). Positive flake scars were discarded because of the numerous bone splinters difficult to localize. Incipient percussion pits are rare (1) and peelings were not noticed, partly due to the poor conservation of the bones surfaces (root etchings). We did not identify adhering flakes in our archaeological sample. Apart from the metapodials, more than half of the scraping marks are associated with impact marks and are thus the result of bone surface preparation for fracturing (S3). For the metapodials, scraping marks may be the result of another unidentified butchering activity (tendons removal or skinning), not necessarily linked to breakage.

Concerning the taxa distribution, megaceros (33%) have by far the highest proportion of percussion notches, followed by horse (29%), red deer and reindeer (25%) (Table 7). Bison (17%) has the lowest number of percussion marks. Notches are more abundant on tibias and humeri (37%) and on femurs (35%) and then metacarpals (22%), metatarsals (20%) and radio-ulnas (18%).

We only observed a few impact marks on the articular portions (portions 1 and 5). This distribution is certainly due to the scarcity of the epiphyses in our sample, but it may also be related to a particular percussion strategies. For most of the long bones, all the surface of the shaft portions 2, 3 and 4 present impact marks (S3). Only three remains of both types of ungulate sizes bear double notches and thus highlighting the existence of counterblows, two right radio-ulnas of reindeer and one right tibia of megaceros.

Most of the notches are shallow (d1 or d2 depth). We identify micro-notches on nearly half of the percussion notches. Nearly the same proportion of micro-notches is observed for each type of depth (S3).

The proportion of percussion marks on medium-sized ungulates is closed to the proportion of large-sized class. For the large-sized ungulates, we recorded 22 percussion notches, which represents a third of the total long bone portions present for this sized-class. They are mostly present on tibias (14). We note a high diversity in location in term of portions and overall surfaces. For the medium-sized ungulates, 197 percussion notches are noted, which represents 27% of the long bone portions for that class. We could also observe a high dispersion of the percussion marks all along the diaphysis for all elements. Despite that, some recurrences may be highlighted, but rarely higher than 50% of the bone portions (Fig. 6).

Humerus remains present a high proportion of percussion notches on the lateral side of each shaft portion. Radio-ulna elements have numerous percussion notches on the anterior side of the shaft portion 4. Metacarpals present a higher proportion of percussion notches on the lateral side of portion 2 and on the mesial side of portions 3 and 4. Femur remains show more notches on the anterior and lateral sides of portion 2 and on the posterior side of portions 3 and 4. Tibias present a high proportion of percussion notches on the anterior side of portion 2, on the anterior and posterior sides of portion 3 and on the lateral side of portion 4. Metatarsal remains present a high proportion of percussion notches on the mesial side of portions 2 and 3 and on the lateral,

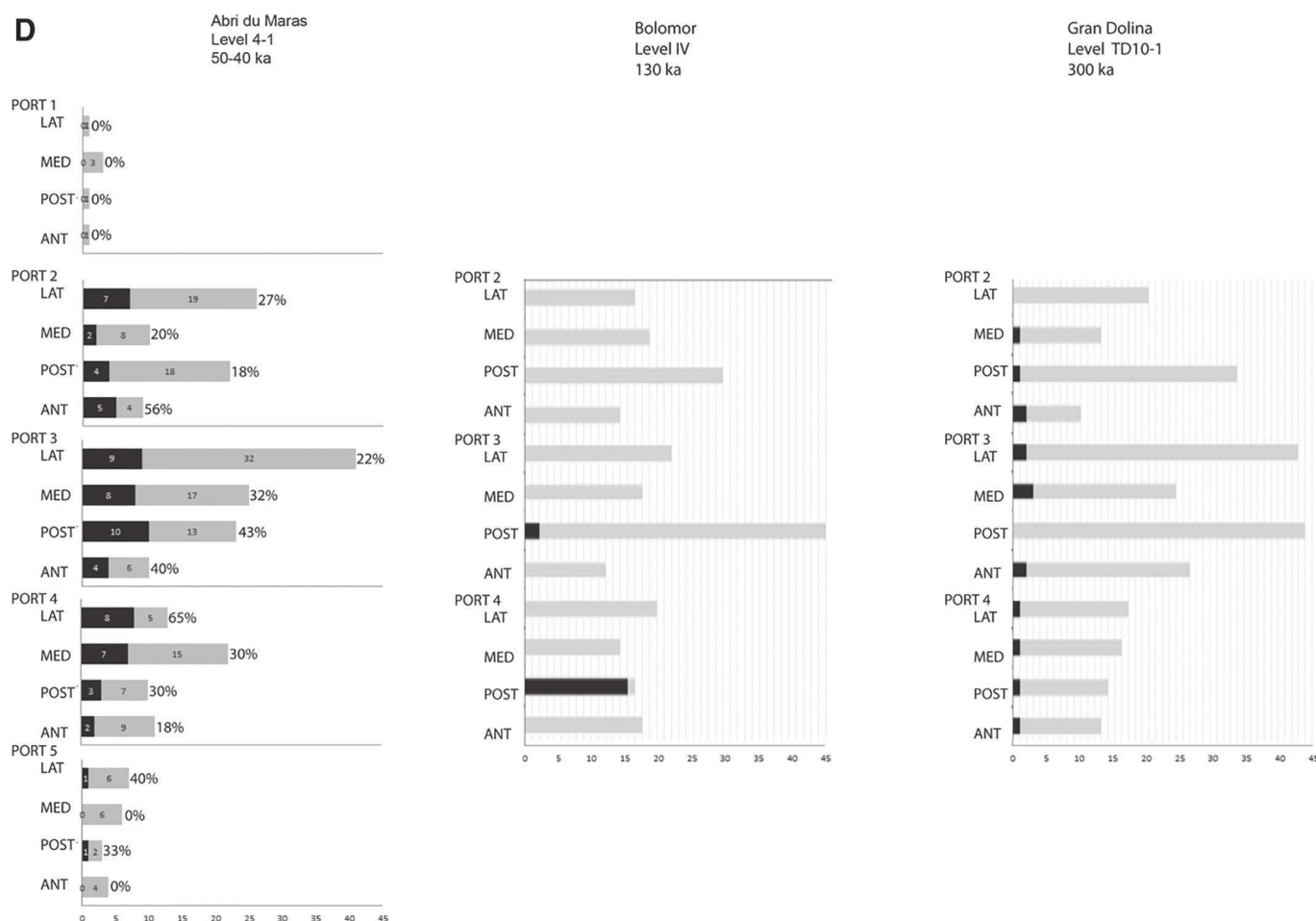


Fig. 6 (continued).

mesial and posterior sides of portion 4. Finally, only a few percussion marks were observed on the articular portions of tibias and metatarsals.

For the medium-sized ungulates, the frequency of scraping marks located in direct association with percussion marks is low for almost all the long bones (less of 10%), with the exception of the radio ulnas (20%) (S3). For the metatarsals no scraping marks is associated with percussion marks. For the large-sized ungulates, only two scraping marks are associated with percussion marks on femur and metatarsal.

The results of the Spearman correlation test show that the negative correlation between bone density and the location of the percussion marks within the long bone shafts (medium-sized ungulates) is not statistically significant ($\rho = -0.178$; $df = 17$; $t = 0.674$, $p > 0.05$).

Regarding tibia and metatarsal percussion marks for the medium-sized ungulates, they have a normal distribution. Inversely, the distribution on humeri, radio-ulnas, femurs and metacarpals does not follow a normal law. About large-sized ungulates, only percussion marks on tibias have a normal distribution. Regarding the totality of our sample, the distribution is homogenous only for tibias and metacarpals. Other long bones have a heterogeneous distribution of the percussion marks along their shafts.

In our sample, Fisher exact tests show that the distributions of percussion marks have not significant trends (Table 8) for both middle and large-sized ungulates and also taking into account all data. They are homogeneously dispersed on the diaphysis, and the differences observed are probably due to random for almost all the long bones in our sample (Table 8).

CA of humeri and tibias show that the individuals with the highest inertia on the first component are Bolomor level IV and Bolomor level XVIIc (Fig. 7). On the second component Bolomor IV and

experimentation by batting have the most inertia. For the radio-ulnas, CA show that on the first component we have individuals with highest inertia, the same as humeri and tibias, but on the second component, Bolomor level XVIIc and experimentation by batting are individuals with the most inertia. We observe on CA of femur that Bolomor level XVIIc and Abri du Maras are individuals contributing the most on the first component and on the second component these are Bolomor level XVIIc and level XVIIa.

5. Discussion: what long bone breakage can tell us about Neandertal technical practices at Abri du Maras?

Within the layer 4-1, long bones are highly fragmented and mostly from anthropic breakage. Green bone fractures predominate and length and circumference analyses confirm the great impact of anthropogenic processes on long bone fragmentation. This is also supported by the quasi-absence of carnivore marks and remains. Sediment pressure

Table 8

Fisher test results for the percussion marks distribution on diaphysis by portion.

	p-Value		
	MUNG	LUNG	Total
Humerus	0.7863	0.3778	0.8295
Radio-Ulna	0.477	1	0.654
Metacarpal	0.3701	0	0.6418
Femur	0.2746	1	0.5062
Tibia	0.1977	0.5017	0.2111
Metatarsal	0.8685	0.1039	0.3492

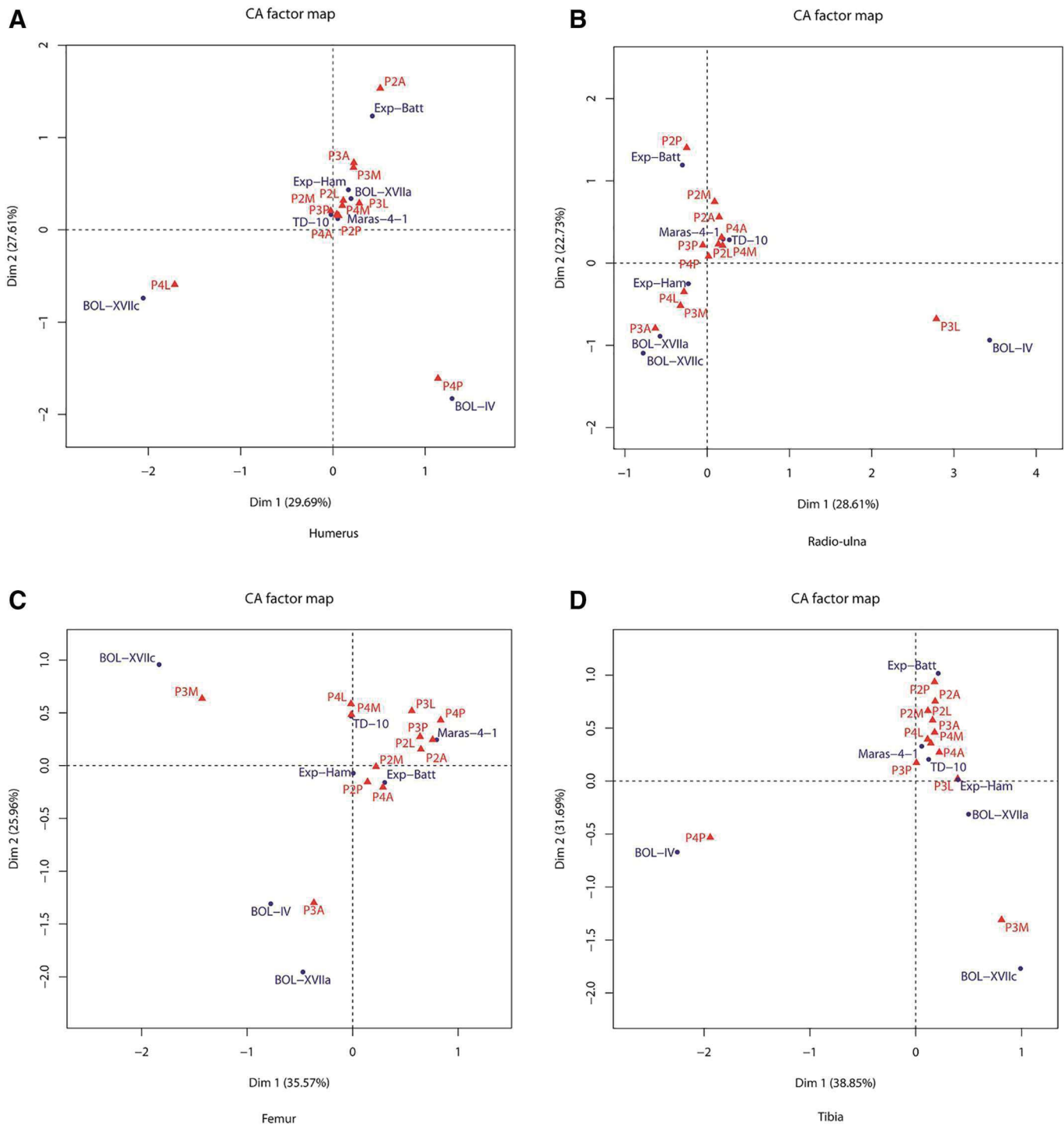


Fig. 7. Humerus, radio-ulna, femur and tibia correspondence analyses showing the location of the breakage marks on the bones (Anterior Portion 2 (P2A), Posterior Portion 2 (P2P), Lateral Portion 2 (P2L) and Medial Portion 2 (P2M) and the same for Portion 3 and Portion 4) in the sites of Maras level 4.1 (Maras-4-1), Bolomor level IV (BOL-IV), Bolomor level XVIIa (BOL-XVIIa), Bolomor level XVIIc (BOL-XVIIc) and Gran Dolina level TD 10-1 (TD-10) and for the experimentation with hammer stone (Exp-Ham) and experimentation by batting (Exp-Batt).

loading and frost action had not a significant influence as fragmentation factors. The only four complete long bones are all metapodials, bones which have a high volume of marrow. This abandonment could be explained by an abundance of prey and the lack of necessity of additional fat or other events difficult to control archaeologically. The occupation of the layer 4-1 mostly occurred during autumn and zooarchaeological analyses highlight mass hunting episodes at that times, thanks to great seasonal reindeer migration (Daujeard, 2008; Daujeard and Moncel, 2010). This abundance of prey is also supported by the presence of anatomical connection, especially for the hind foot elements in

this layer. Thus, in such a context of food profusion, Neandertals have abandoned some parts of animals, without intensively exploited them for their marrow. This had direct incidence on long bone breakage strategy, in term of systematic behaviour. Anyway, the long bone breakage at Abri du Maras layer 4-1 still appears quite intensive and suggests that Neandertals largely exploited the marrow as an important source of fat.

Large-sized ungulates have the highest rates of percussion marks by long bone portions, with almost a third of them. For the medium-sized ungulates, about a quarter of their long bone portions bear notches or impact flakes. For all type of ungulates, percussion marks are distributed

throughout the diaphysis. The distribution does not seem to be related to the density of the bone portions or to any particular location. Indeed, statistical analyses show no systematic distribution of percussion marks along the shafts. Neandertals did not preferentially hit bones on the less dense parts of diaphyses, nor seem to have chosen a particular way of breakage. Indeed, the apparent percussion marks dispersion along the shafts at Abri du Maras 4-1 (beginning of the MIS 3) is comparable to that of Gran Dolina TD10-1 (MIS 9) and in some cases to the level XVIIa of Bolomor (Fig. 6, Blasco et al. 2013). Their location close to zero on both axis of the factorial map of the CA also highlights that bones in these sites do not show preferential location of percussion marks (Fig. 7). Inversely, specific patterns, in particular standardization and counter-intuitive gestures observed in the level IV of Bolomor (MIS 5e), were not identified at Abri du Maras. Indeed, we see that Bolomor level IV is far from the other series for all bone elements. In this site, percussion marks are rather localized close to distal posterior portion for humeri and tibia on lateral mid-shaft for radio-ulnas and on anterior mid-shaft for femurs. In Bolomor level XVIIc, percussion marks are close to distal posterior portion for humeri and to medial mid-shaft in femurs and tibias. On radio-ulnas, it is close to anterior mid-shaft, like for Bolomor level XVIIa.

The graphs of CA show no particular pattern for the hammer-stone experimental methods (Fig. 7). It seems to have some regularity for the batting method for the humeri, radio-ulnas and tibias. Non-trained experimenters may have hit those bones in the same way, holding them by the distal part. This pattern could result from a morphological choice – that is, an easier way to hold the bone. Blasco et al. (2014a, p. 1087) reported that “all of the experimenters held the bones by the narrower end and hit them near the wider end following intuitive criteria, based on bone morphology and easiness/comfort of holding the skeletal element with the hands”. In this case, there was no specific manner to present bones to experimenters, thus the regularity of this bone breakage technique seems not to be associated with the experimental protocol. For femurs, the batting method is much closer to distal anterior portion, but also closed to zero and not very significant. Anyway, the archaeological data for Abri du Maras, as well as the other fossil series, appear distant from the batting experimental methods. In case of a morphological choice, the batting method did not have to be used exclusively in any archaeological sites. The long bones were broken either by the hammer-stone method or by a mix of both, if individuals use an intuitive gesture.

In conclusion, we do not observe standardized breakage pattern at Abri du Maras 4-1 regarding the notches distribution along the shaft. That circumstance may respond here to two different hypotheses: 1) the presence of several groups bearing various butchery practices during the sedimentary formation and the marked palimpsest character of this layer or 2) the presence of individuals of one single group which do not share any butchery traditions.

Therefore, we have no proof of intergenerational transmission of a technical know-how as regards to the bone breakage practices at Abri du Maras and we certainly are in presence of occupations palimpsest by different cultural groups.

However, at the Abri du Maras, the autumnal reindeer mass predation could be a good indicator of the sharing of traditions between groups, including intergenerational transmission of the topographical and environmental knowledge for this shelter. Besides that, the preponderance of reindeer within our sample and throughout the layer 4-1, associated with recurrent autumnal occupations, clearly illustrates a choice by the occupants of the rock shelter (Daujeard and Moncel, 2010). The choice of the reindeer as the main meat resource may also signify that the group(s) using the shelter deliberately came for selective reindeer hunting (see discussion above). As most of them died during the autumn, they would have known the habitual migration routes of this gregarious species. These indicators could contribute to enhancing our understanding of the reasons for the choice of the site, located near a ford and the mouth of the Ardèche River. Given the recurrence

of the occupations, it is thus possible to envisage that the localization and attributes of the site would have been passed on from one group to another or within the same group over several generations. Because the layer 4-1 is a palimpsest of several occupations, maybe more than thirteen (ash lenses), in this case the hypothesis of an intergenerational transmission of the site localisation and surrounding advantages could be proposed.

Concerning the lithic technology, the assemblages are composed of elongated Levallois flakes, flakes, points and cores and small flakes produced by small Levallois core on flakes on site (Moncel et al. 2014). The Levallois core technology is widely dominant in the series and corresponds to the Levallois core technology observed at the MIS 4 and 3 in the area (mainly unipolar). The specificity of Abri du Maras is the elongated and pointed end-products mainly used for the Late Middle Palaeolithic (Moncel et al., 2014) Neandertals occupying the Abri du Maras used mainly a Levallois technology that shows presence of one group or many groups sharing the same lithic practices. It seems that at Abri du Maras we observed the presence of an intergenerational transmission of knowledge for lithic technology. Moreover, the lithic strategies are coherent in this level and we cannot consider that, even if the series is the palimpsest of several occupations, the assemblage gather groups of different lithic traditions. The lithic series offers the opportunity to observe a tool kit which seems to be related to similar and recurrent activities performed at the site.

Whatever, several groups sharing the same lithic technology (Levallois) but with different butchery techniques could have met at Abri du Maras to conduct a mass predation during autumn.

We need a more fine-grained analysis of technical variability to identify more discrete spatial and temporal units, showing standardized patterns specific to certain regions or sites, to approach social entities. Identification of small-scale standardized patterns in both subsistence and technology opens an interesting avenue for future researches.

6. Conclusion

In our opinion, cutting incision does not seem to be the best way to analyse standardized butchery practices, mainly because of the influences of butcher dexterity, animal (morphology and size) and raw materials used, on the frequency and location of cut marks (Blasco et al. 2013). Indeed, cutting incisions in case of defleshing, disarticulating or even skinning may be very scarce when good and experimented butchers produce them. For example, in southeastern France, at the Early Middle Palaeolithic site of Orgnac 3, during the course of the sequence comprising ten occupation phases dating from MIS 9 to MIS 8, the rarefaction of butchery striations in the levels at the top of the sequence would indicate improved butchery techniques, linked to increased dexterity (Moncel et al. 2012).

Inversely, scraping marks are intentionally made during the bone surface cleaning (removing the periosteum), and consequently do not depend on the dexterity of the butcher. They are thus a potentially significant source of information for the identification of butchery practices. Their study related to the analysis of percussion marks could bring additional information to a better understanding of butchery tradition. In fact, at Abri du Maras, their frequency may indicate the recurrent use of certain breakage practices and thus the existence of a particular butchery culture.

In the same way, long bone breakage processes have already revealed their potential in the understanding of Neandertal butchery traditions (Blasco et al., 2013). Unfortunately, the results of this study for the layer 4-1 of Abri du Maras do not highlight specific butcher tradition in term of bone percussion strategies. We did not observe specific butchery practices that would have been shared by a same group returning several times in the site during the sedimentary filling. Due to the paucity of such studies and the rarity of comparative series, it is not currently possible to draw conclusions as to a possible chronological or geographical trend of cultural butchery traditions. Moreover, the

big chronological gap existing between Gran Dolina TD-10 (upper part) and the two other sites, contemporaneous of the late Middle Palaeolithic, adds to this difficulty. For example, at Gran Dolina level TD 10-1, no hearth was found, contrary to the two other sites, where fire could potentially be used during the breakage process. However, we did not observe such practices in level 4.1 of Abri du Maras.

The question of identifying Middle Palaeolithic butchery traditions within Neandertal groups is central to a better understanding of inter-generational transmission practices. This research provides new data concerning the relation between meat consumption and the socio-cultural context of these human groups: learning of butchery techniques, systematization of gesture and dexterity in carcass processing. Based on a zooarchaeological study of faunal remains and specifically on the percussion marks analysis for the Middle Palaeolithic in Europe, it will be possible to test the hypothesis of the existence of various Neandertal butchery traditions at a large geographical scale, in parallel to technological traditions. It could be also possible to estimate the period and context (climate, environment, geographical area and type of human occupation) of the appearance of such a butchering know-how. For all that reasons, it seems necessary to increase the number of this type of study on many other Middle Palaeolithic sites. In the same way, to better take into account the impact of the animal size and morphology on carcass processing and specifically on bone fracturing, it will be also interesting to increase the experimental data corpus including various species.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <http://dx.doi.org/10.1016/j.jasrep.2017.03.029>.

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Annexes 3

Supplementary data

*Approche techno-culturelle de la fracturation des os longs chez les Néandertaliens (Sud-Ouest de l'Europe, MIS 5-3) :
une systématisation des gestes ?*

Supplementary data 1. MAU for MUNG and LUNG and density indexes by portions (Lam et al., 1999). The first part is the element concerned: Humerus (HUM), Radio-ulna (RAD), Metacarpal (METC), Femur (FEM), Tibia (TIB) and Metatarsal (MET); the second part is the portion: P1, P2, P3, P4 and P5.

	MUNG			LUNG		
	MAU	%MAU	Density indexes	MAU	%MAU	Density indexes
HUMP1	0.5	2%	0.26	0	0%	0.23
HUMP2	6.5	8%	0.44	1.5	15.0%	0.33
HUMP3	27.5	34%	1.12	2	20.0%	1.1
HUMP4	35.5	55%	1.08	1.5	15.0%	1.05
HUMP5	11	15%	0.48	0.5	5.0%	0.36
RADP1	10.5	13%	0.53	0	0%	0.37
RADP2	24.5	21%	1.08	0	0%	1.04
RADP3	58	66%	1.09	3	30.0%	1.08
RADP4	8	8%	0.97	2	20.0%	1
RADP5	2.5	3%	0.49	0	0%	0.42
METCP1	14	15%	0.92	1	10.0%	0.3
METCP2	14.5	18%	1.08	2	20.0%	0.99
METCP3	18	31%	1.1	1.5	15.0%	1.09
METCP4	12	13%	1.01	1	10.0%	0.51
METCP5	9.5	8%	0.68	0	0%	0.3
FEMP1	0	0%	0.52	1	10.0%	0.55
FEMP2	6.5	11%	0.74	1	10.0%	1.03
FEMP3	20.5	27%	1.15	0.5	5.0%	1.1
FEMP4	10.5	19%	0.61	0.5	5.0%	0.71
FEMP5	0	0%	0.32	0.5	5.0%	0.6
TIBP1	3	5%	0.35	0.5	5.0%	0.3
TIBP2	33.5	42%	1.01	5.5	55.0%	0.77
TIBP3	49.5	66%	1.13	10	100.0%	1.07
TIBP4	28.5	37%	1.12	2.5	25.0%	1.05
TIBP5	10	11%	0.73	0	0%	0.45
METTP1	11.5	16%	0.9	5	50.0%	0.59
METTP2	20	31%	1.1	6.5	65.0%	1.07
METTP3	46	100%	1.08	2	20.0%	1.1
METTP4	16.5	24%	1.08	2.5	25.0%	0.71
METTP5	5	6%	0.59	2	20.0%	0.6

Supplementary data 2. Number of Portion (NP), Number of Portion with cut marks (NPcum), Number of Portion with Incision marks (INC), with Scrapping marks (SCRAP), with Indeterminate cut marks, Number of Portion with disarticulation (Dis), cutting (Cut), defleshing (Def), skinning (Skin) and perioste removal (Pr) marks for MUNG and LUNG.

			NP		INC		SCRAP		Ind		Di	Df	Cut	Sk	Pr	Ind	
			NP	%	NP	%	NP	%	NP	%							
MUNG	Humerus	P1	1	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		P2	13	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		P3	55	8	25.0%	3	37.5%	2	25.0%	3	37.5%	0	1	1	0	2	3
		P4	71	10	22.7%	7	70.0%	1	10.0%	2	20.0%	3	5	0	0	1	2
		P5	22	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		Total	97	17	33.3%	11	64.7%	3	17.6%	3	17.6%	3	6	1	0	3	3
	Radio-ulna	P1	21	2	11.8%	1	50.0%	1	50.0%	0	0%	0	0	1	0	1	0
		P2	49	10	23.8%	8	80.0%	2	20.0%	0	0%	1	2	4	0	2	0
		P3	116	17	15.9%	12	70.6%	4	23.5%	1	5.9%	0	5	7	0	4	1
		P4	16	3	20.0%	1	33.3%	2	66.7%	0	0%	0	1	0	0	2	0
		P5	5	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		Total	123	31	29.8%	21	67.7%	9	29.0%	1	3.2%	1	7	12	0	9	1
	Metacarpal	P1	28	1	4.5%	0	0%	1	100.0%	0	0%	0	0	0	0	1	0
		P2	29	8	33.3%	4	50.0%	4	50.0%	0	0%	0	2	0	4	4	0
		P3	36	12	37.5%	8	66.7%	2	16.7%	2	16.7%	0	1	0	6	2	2
		P4	24	2	10.0%	2	100.0%	0	0%	0	0%	0	0	0	2	0	0
		P5	19	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		Total	58	23	50.0%	13	56.5%	6	26.1%	4	17.4%	0	2	0	8	6	4
	Femur	P1	0	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		P2	13	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		P3	41	14	45.2%	10	71.4%	1	7.1%	3	21.4%	0	7	0	0	1	3
		P4	21	3	20.0%	3	100.0%	0	0%	0	0%	1	3	0	0	0	0
		P5	0	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		Total	45	16	59.3%	12	75.0%	1	6.3%	3	18.8%	1	9	0	0	1	3
	Tibia	P1	6	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		P2	67	16	28.1%	16	100.0%	0	0%	0	0%	3	11	4	0	0	0
		P3	99	26	31.0%	21	80.8%	5	19.2%	0	0%	0	17	4	0	5	0
		P4	57	15	35.7%	12	80.0%	3	20.0%	0	0%	1	7	5	0	3	0
		P5	20	3	18.8%	2	66.7%	0	0%	1	33.3%	0	0	1	0	0	1
		Total	184	58	40.6%	50	86.2%	7	12.1%	1	1.7%	4	34	14	0	7	1
	Metatarsal	P1	23	0	0%	0	0%	0	0%	0	0%	0	0	1	0	0	0
		P2	40	7	21.9%	6	85.7%	1	14.3%	0	0%	0	0	2	5	1	0
		P3	92	21	26.9%	18	85.7%	3	14.3%	0	0%	0	2	2	16	3	0
		P4	33	11	40.7%	11	100.0%	0	0%	0	0%	1	0	5	7	0	0
		P5	10	1	10.0%	1	100.0%	0	0%	0	0%	0	0	1	0	0	0
		Total	167	50	35.5%	44	88.0%	6	12.0%	0	0%	2	2	14	31	6	0
	Metapodial	P1	3	2	100%	1	50.0%	0	0%	1	50.0%	0	0	0	0	0	1
		P2	0	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		P3	13	10	0%	10	100.0%	0	0%	0	0%	0	1	2	7	0	0
		P4	3	1	33.3%	1	100.0%	0	0%	0	0%	0	0	0	1	0	0
		P5	4	0	0%	0	0%	0	0%	0	0%	0	0	1	0	0	0
		Total	68	16	32.0%	15	93.8%	0	0%	1	6.3%	0	1	4	8	0	1
		Total	742	211	37.5%	166	78.7%	32	15.2%	13	6.2%	11	61	45	47	32	13

Approche techno-culturelle de la fracturation des os longs chez les Néandertaliens (Sud-Ouest de l'Europe, MIS 5-3) :
une systématisation des gestes ?

		NP	NPcm		INC		SCRAP		Ind		Di	Df	Cut	Sk	Pr	Ind	
			NP	%	NP	%	NP	%	NP	%							
LUNG	Humerus	P1	0	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		P2	3	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		P3	4	1	25.0%	1	100.0%	0	0%	0	0%	1	1	0	0	0	0
		P4	3	1	33.3%	1	100.0%	0	0%	0	0%	1	0	0	0	0	0
		P5	1	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		Total	5	2	50.0%	2	100.0%	0	0%	0	0%	2	1	0	0	0	0
	Radio-ulna	P1	0	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		P2	0	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		P3	6	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		P4	4	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		P5	0	1	0%	1	100.0%	0	0%	0	0%	0	1	0	0	0	0
		Total	8	1	20.0%	1	100.0%	0	0%	0	0%	0	1	0	0	0	0
	Metacarpal	P1	2	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		P2	2	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		P3	1	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		P4	1	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		P5	1	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		Total	2	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
	Femur	P1	2	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		P2	4	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		P3	3	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	1
		P4	2	1	100.0%	1	100.0%	0	0%	0	0%	0	1	0	0	0	0
		P5	0	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		Total	9	1	50.0%	1	100.0%	0	0%	1	100.0%	0	1	0	0	0	1
	Tibia	P1	1	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		P2	11	1	12.5%	0	0%	1	100.0%	0	0%	0	0	0	1	0	
		P3	19	7	50.0%	6	85.7%	1	14.3%	0	0%	0	5	1	0	1	0
		P4	5	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		P5	0	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		Total	28	8	38.1%	6	75.0%	2	25.0%	0	0%	0	5	1	0	2	0
	Metatarsal	P1	10	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		P2	13	3	37.5%	2	66.7%	1	33.3%	0	0%	1	0	0	2	1	0
		P3	4	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		P4	5	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		P5	4	0	0%	0	0%	0	0%	0	0%	0	0	0	0	0	0
		Total	14	3	37.5%	2	66.7%	1	33.3%	0	0%	1	0	0	2	1	0
Total	66	13	31.7%	10	76.9%	2	15.4%	1	7.7%	2	8	1	0	2	1		

Supplementary data 3. Number of Portions (NP), Number of Portion with green bone fracture (NPgf), with dry bone fracture (NPdf) and with indeterminate bone fracture (NPif), Number of Portion with Percussion Marks: notches (NPM), Number of scrapping marks related with Percussion marks NPscrap, depth of notches and Number of micro-notches according the depth.

			NP	NPgf	NPdf	NPif	PM		Scrap (as. Pm)		d1		d2		d3		
							Npm	τ Npm	Nbscrap	% Scrap/Pm	NP	μnotches	NP	μnotches	NP	μnotches	
MUNG	Humerus	P1	1	1	0	0	0	0%	0	0%	0	0	0	0	0	0	0
		P2	13	10	2	1	2	15.4%	0	0%	0	0	0	0	0	0	0
		P3	55	44	8	5	16	29.1%	1	6.3%	5	2	2	1	1	1	1
		P4	71	55	13	6	17	23.9%	0	0%	4	2	6	3	1	0	0
		P5	22	18	7	1	0	0%	0	0%	0	0	0	0	0	0	0
Total			97	90	21	9	35	36.1%	1	2.9%	9	4	8	4	2	1	1
Radio-ulna	P1	21	12	7	4	0	0%	0	0%	1	0	0	0	0	0	0	0
	P2	49	32	9	7	6	12.2%	1	16.7%	0	0	1	1	1	0	0	
	P3	116	79	32	10	15	12.9%	2	13.3%	3	1	4	2	2	0	0	
	P4	16	13	4	2	4	25.0%	1	25.0%	2	0	1	0	0	0	0	
	P5	5	4	2	0	0	0%	0	0%	0	0	0	0	0	0	0	0
Total			123	110	44	18	25	20.3%	5	20.0%	6	1	6	3	3	0	0
Metacarpal	P1	28	15	2	4	0	0%	0	0%	0	0	0	0	0	0	0	0
	P2	29	16	4	4	5	17.0%	0	0%	1	1	3	0	0	0	0	
	P3	36	23	6	3	7	19.0%	0	0%	1	1	3	1	4	2	2	
	P4	24	14	5	2	3	12.5%	0	0%	2	1	0	0	2	1	1	
	P5	19	6	1	0	0	0%	0	0%	0	0	0	0	0	0	0	0
Total			58	52	11	7	15	25.9%	1	6.7%	4	3	6	1	6	3	3
Femur	P1	0	0	0	0	0	0%	0	0%	0	0	0	0	0	0	0	0
	P2	13	11	2	2	5	38.0%	0	0%	1	1	0	0	1	1	1	
	P3	41	33	3	5	8	21.0%	1	12.5%	3	1	2	2	1	0	0	
	P4	21	14	4	2	3	14.0%	0	0%	0	0	2	2	0	0	0	
	P5	0	0	0	0	0	0%	0	0%	0	0	0	0	0	0	0	0
Total			45	45	6	6	16	35.6%	1	6.3%	5	3	4	4	2	1	1
Tibia	P1	6	1	0	2	0	0%	0	0%	0	0	0	0	0	0	0	0
	P2	67	48	10	4	18	27.0%	0	0%	9	4	4	0	3	1	1	
	P3	99	101	20	6	31	31.0%	3	9.7%	11	5	15	7	6	2	2	
	P4	57	46	12	5	20	35.0%	2	10.0%	8	6	8	6	2	1	1	
	P5	20	15	7	3	1	5.0%	0	0%	1	1	0	0	0	0	0	0
Total			184	179	40	16	70	38.0%	5	7.1%	29	16	28	14	11	4	4
Metatarsal	P1	23	17	7	7	2	9.0%	0	0%	2	1	0	0	0	0	0	
	P2	40	31	17	10	11	26.0%	0	0%	6	3	1	0	0	0	0	
	P3	92	105	45	16	14	15.0%	0	0%	7	2	4	1	2	1	1	
	P4	33	34	14	4	8	25.0%	0	0%	0	0	1	0	1	1	1	
	P5	10	7	1	1	0	0%	0	0%	0	0	0	0	0	0	0	0
Total			167	156	65	28	35	21.0%	0	0%	16	7	6	1	3	2	2
Metapodial	P1	3	2	0	0	1	33.0%	0	0%	0	0	0	0	0	0	0	0
	P2	0	0	0	0	0	0%	0	0%	0	0	0	0	0	0	0	0
	P3	13	42	29	6	0	0%	0	0%	0	0	0	0	0	0	0	0
	P4	3	6	2	0	0	0%	0	0%	0	0	1	1	0	0	0	0
	P5	4	1	1	0	0	0%	0	0%	0	0	0	0	0	0	0	0
Total			68	50	34	7	1	1.5%	0	0%	0	0	1	1	0	0	0
Total			742	682	221	91	197	26.5%	13	6.6%	69	34	59	28	27	11	11

Approche techno-culturelle de la fracturation des os longs chez les Néandertaliens (Sud-Ouest de l'Europe, MIS 5-3) : une systématisation des gestes ?

			NP	NPgf	NPdf	NPif	PM		Scrap (as. Pm)		d1		d2		d3			
							Npm	τ Npm	Nbscrap	% Scrap/Pm	NP	μnotches	NP	μnotches	NP	μnotches		
LUNG	Humerus	P1	0	0	0	0	0	0%	0	0%	0	0	0	0	0	0	0	
		P2	3	2	0	0	0	0%	0	0%	0	0	0	0	0	0	0	
		P3	4	3	1	0	1	33.3%	0	0%	0	0	0	0	0	1	1	
		P4	3	2	1	0	1	33.3%	0	0%	0	0%	1	0	0	0	0	0
		P5	1	1	0	0	0	0%	0	0%	0	0%	0	0	0	0	0	0
Total			5	5	1	0	2	40.0%	0	0%	1	0	0	0	0	1	1	
Radio-ulna	P1	0	0	0	0	0	0%	0	0%	0	0	0	0	0	0	0	0	
	P2	0	0	0	0	0	0%	0	0%	0	0	0	0	0	0	0	0	
	P3	6	3	1	0	1	16.7%	0	0%	0	0	0	0	0	1	1		
	P4	4	3	1	0	0	0%	0	0%	0	0%	0	0	0	0	0	0	
	P5	0	0	0	0	0	0%	0	0%	0	0%	0	0	0	0	0	0	
Total			8	7	2	0	1	12.5%	0	0%	0	0	0	0	1	1		
Metacarpal	P1	2	0	1	0	0	0%	0	0%	0	0	0	0	0	0	0	0	
	P2	2	0	1	0	0	0%	0	0%	0	0	0	0	0	0	0	0	
	P3	1	0	0	0	0	0%	0	0%	0	0	0	0	0	0	0	0	
	P4	1	0	0	0	0	0%	0	0%	0	0	0	0	0	0	0	0	
	P5	1	0	0	0	0	0%	0	0%	0	0%	0	0	0	0	0	0	
Total			2	0	1	0	0	0%	0	0%	0	0	0	0	0	0	0	
Femur	P1	2	1	0	0	0	0%	0	0%	0	0	0	0	0	0	0	0	
	P2	4	4	2	0	1	25.0%	0	0%	0	0	0	0	0	0	0	0	
	P3	3	3	2	0	2	67.0%	1	50.0%	0	0	1	0	0	0	0	0	
	P4	2	2	1	0	0	0%	0	0%	0	0%	0	0	0	0	0	0	
	P5	0	0	0	0	0	0%	0	0%	0	0%	0	0	0	0	0	0	
Total			9	9	3	0	3	33.3%	1	33.3%	2	2	2	2	0	0		
Tibia	P1	1	0	1	0	0	0%	0	0%	0	0	0	0	0	0	0	0	
	P2	11	9	3	0	4	36.0%	0	0%	2	1	1	0	0	0	0		
	P3	19	16	5	1	7	37.0%	0	0%	4	1	3	2	1	0	0		
	P4	5	4	4	0	3	40.0%	0	0%	1	0	0	0	1	1	1		
	P5	0	0	0	0	0	0%	0	0%	0	0%	0	0	0	0	0	0	
Total			28	26	9	1	14	50.0%	0	0%	8	3	4	2	2	1		
Metatarsal	P1	10	5	4	2	0	0%	0	0%	0	0	0	0	0	0	0	0	
	P2	13	7	4	2	0	0%	0	0%	0	0	0	0	0	0	0	0	
	P3	4	1	1	0	2	50.0%	0	0%	1	1	0	0	0	0	0		
	P4	5	4	2	0	0	0%	0	0%	0	0	0	0	0	0	0	0	
	P5	4	0	1	0	0	0%	0	0%	0	0%	0	0	0	0	0	0	
Total			14	12	5	4	2	14.3%	0	0%	1	1	0	0	0	0		
Total			66	59	21	5	22	33.3%	1	4.5%	11	5	6	4	4	3		

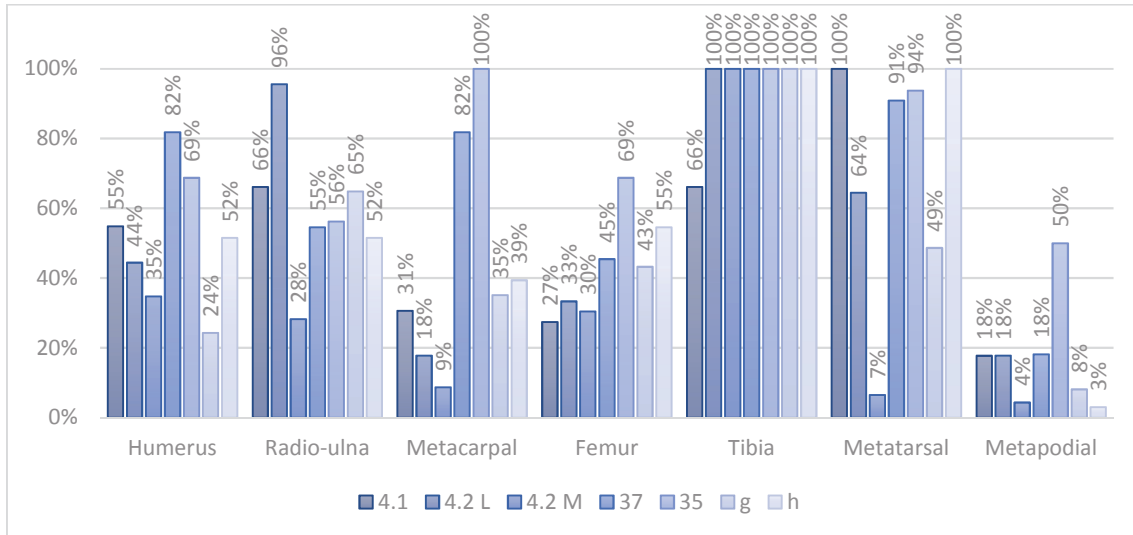
Annexes 4

Supplementary data

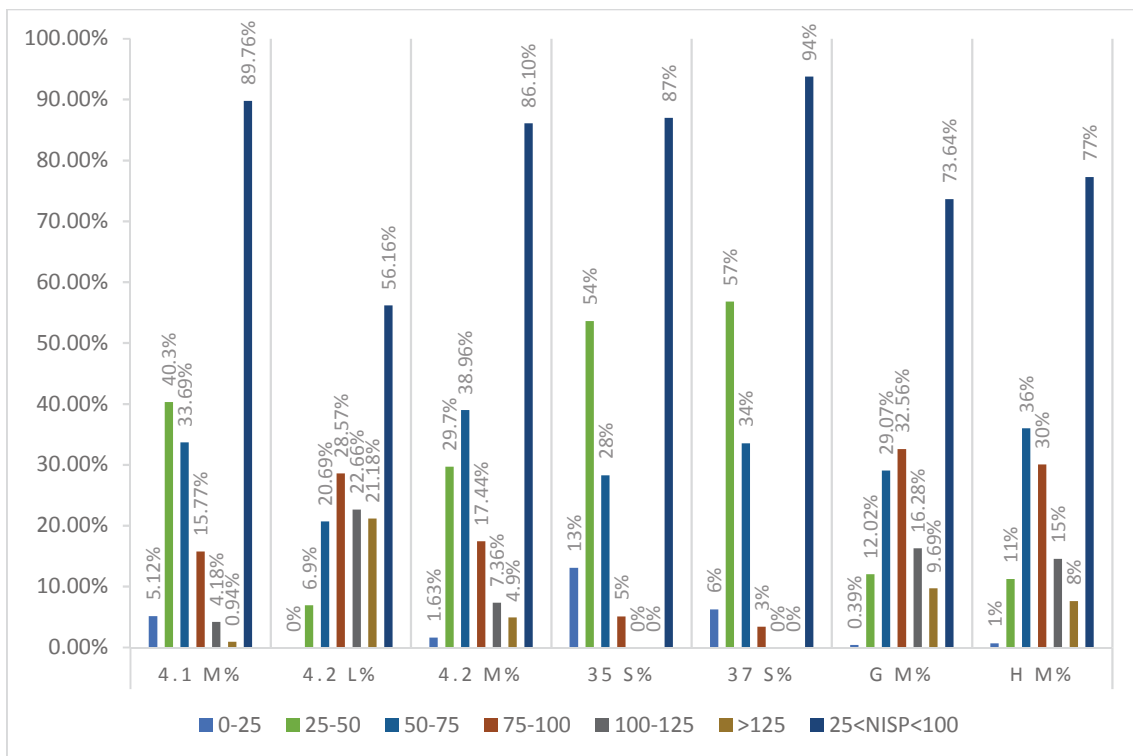
Supplementary data 1. Mains size categories regarding the species involved in our analyses.

SUNG	10-100 kg	Roe deer, chamois and ibex
MUNG	100-200 kg	Reindeer and red deer
LUNG	200-1000 kg	Horse, bison, elk, megaceros

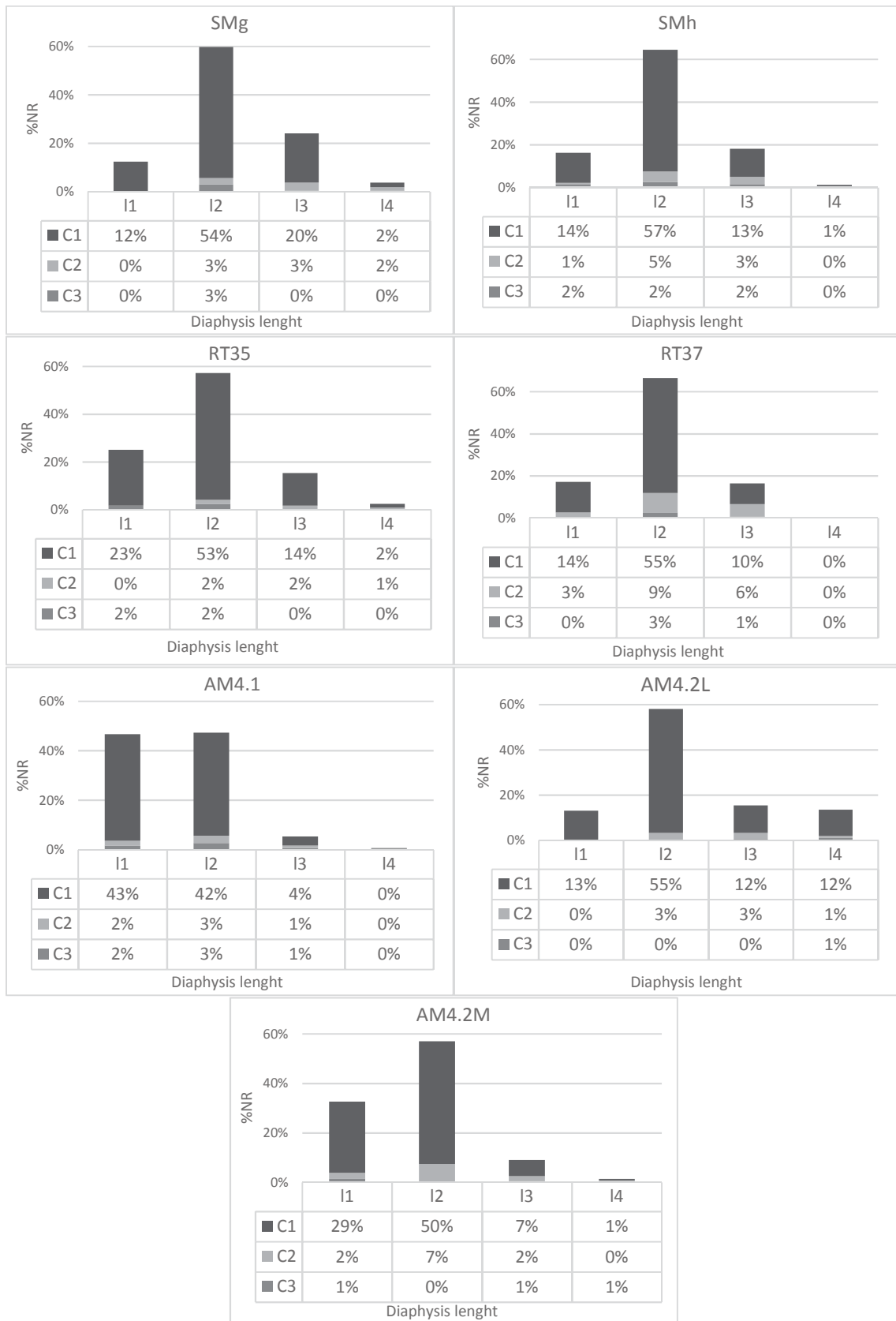
Supplementary data 2. % MAU regarding each element for each layer of the studied sites.



Supplementary data 3. NISP values for each of the measurement intervals along the length of the bone.



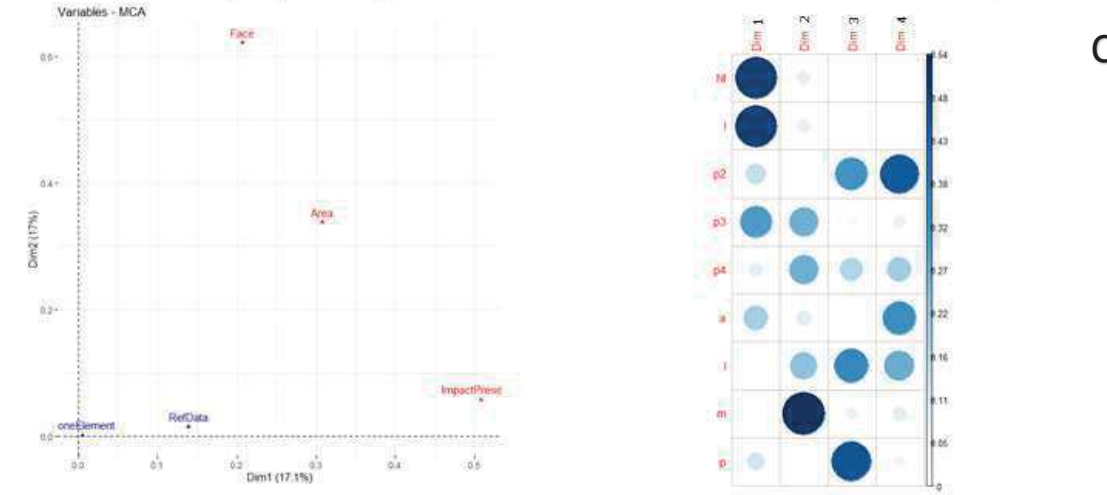
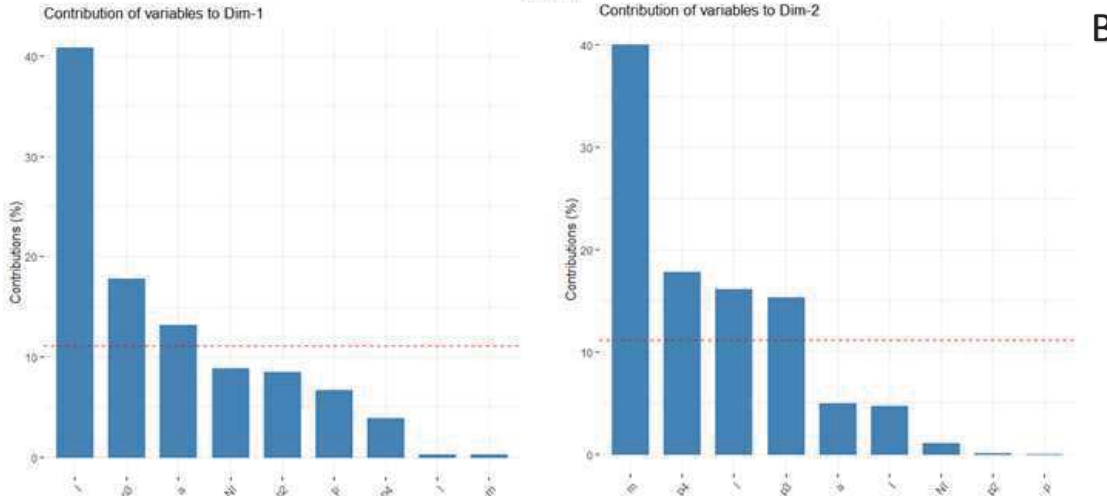
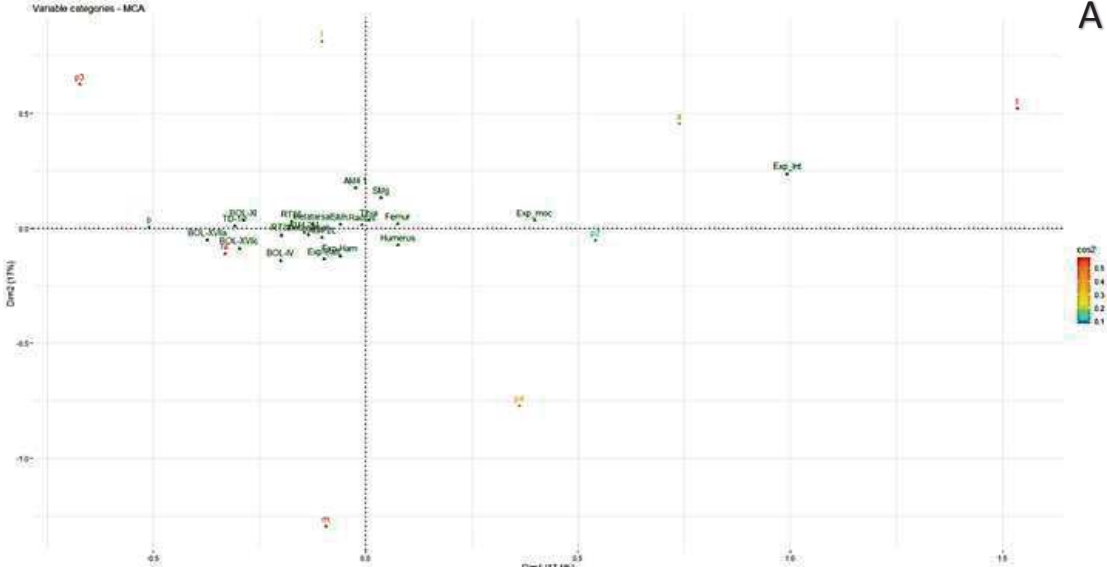
Supplementary data 4. Diagram showing relative frequencies of shaft length and circumference for each layers of our sample of long bone elements



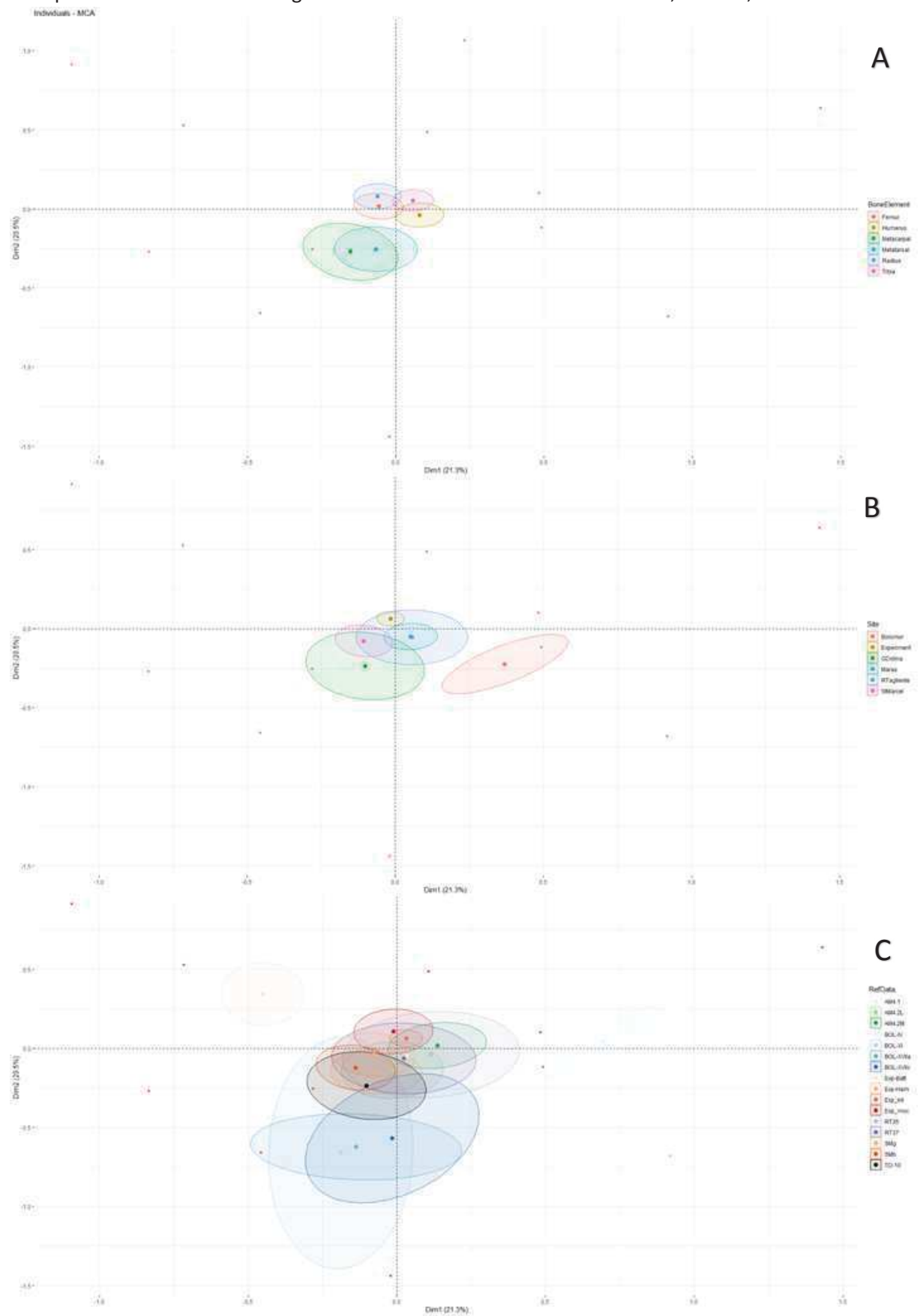
Supplementary data 5. Number of portion by element (NP), number of percussion marks by portion (NPPM) by element and ratio of NP/NPPM; for each site and layer.

Sites		Abri du Maras									Saint Marcel cave						Riparo Tagliante					
Layer		4.1			4.2 LUNG			4.2 MUNG			g			h			35			37		
		NP	NPPM	NPPM/NP	NP	NPPM	NPPM/NP	NP	NPPM	NPPM/NP	NP	NPPM	NPPM/NP	NP	NPPM	NPPM/NP	NP	NPPM	NPPM/NP	NP	NPPM	NPPM/NP
Humerus	total	97	32	32.99%	32	20	62.50%	41	15	36.59%	18	10	55.56%	30	15	0.5	18	6	33.33%	18	11	61.11%
	p1	1	0		0	0		0	0		0	0		0	0		0	0		0	1	0%
	p2	13	2	15.38%	6	1	16.67%	8	1	0%	6	2	33.33%	6	1	16.67%	4	0	0%	5	2	40%
	p3	55	16	29.09%	16	7	43.75%	18	6	33.33%	9	4	44.44%	17	4	23.53%	9	3	33.33%	9	2	22.22%
	p4	71	17	23.94%	14	4	28.57%	20	3	15%	8	2	25%	15	3	20%	3	2	66.67%	11	2	18.18%
p5	22	0	0%	3	0	0%	3	0	0%	0	0	0%	0	0	0%	1	0	0%	3	0	0%	
Radio-ulna	total	123	22	17.89%	29	8	27.59%	79	21	27%	41	22	53.66%	43	13	30.23%	5	2	40%	13	2	15.38%
	p1	21	0	0%	2	1	50%	4	0	0%	4	1	25%	5	0	0%	1	0	0%	2	0	0%
	p2	49	6	12.24%	10	0	0%	29	2	6.9%	21	7	33.33%	14	2	14.29%	3	0	0%	5	1	20%
	p3	116	15	12.93%	13	2	15.38%	43	8	18.6%	24	4	17%	8	3	37.50%	6	1	17%	9	1	11.11%
	p4	16	4	25%	8	2	25%	19	3	15.79%	8	2	25%	3	3	100%	2	1	50%	6	1	16.67%
p5	5	0	0%	1	0	0%	2	0	0%	3	0	0%	5	1	20%	0	0	0%	0	0	0%	
Metacarpal	total	58	13	22.41%	6	1	16.67%	23	7	30%	31	27	87.10%	45	26	57.78%	32	15	46.88%	33	11	33.33%
	p1	28	0	0%	3	0	0%	4	0	0%	2	0	0%	2	0	0%	0	0	0%	0	0	0%
	p2	29	5	17.24%	4	1	25%	7	1	14.29%	10	4	40%	12	5	41.67%	7	1	14.29%	1	1	100%
	p3	36	7	19.44%	3	0	0%	8	2	25%	13	5	38.46%	18	4	0%	9	0	0%	16	1	6.25%
	p4	24	3	12.5%	4	0	0%	6	1	16.67%	12	5	41.67%	15	1	7%	7	2	28.57%	6	2	33.33%
p5	19	0	0%	1	0	0%	1	0	0%	1	0	0%	0	0	0%	2	0	0%	3	0	0.00%	
Femur	total	45	16	35.56%	29	14	48.28%	32	10	31%	32	13	40.63%	36	19	52.78%	15	7	46.67%	22	10	45.45%
	p1	0	0	0%	1	0	0%	3	0	0%	3	0	0%	2	0	0%	2	0	0%	1	1	100%
	p2	13	5	38.46%	7	3	42.86%	12	3	25%	12	4	33.33%	0	4	0%	4	1	25%	5	1	20%
	p3	41	8	19.51%	14	6	42.86%	16	3	18.75%	16	4	25%	2	5	250%	5	3	60%	8	2	25%
	p4	21	3	14.29%	8	2	25%	14	2	14.29%	14	2	14.29%	6	2	33.33%	2	0	0%	11	1	9%
p5	0	0	0%	0	0	0%	1	0	0%	1	0	0%	18	0	0%	18	0	0%	3	0	0%	
Tibia	total	184	65	35.33%	93	32	34.4%	95	38	40.00%	64	33	51.56%	60	22	36.67%	20	10	50%	39	16	41.03%
	p1	6	0	0%	10	1	10%	7	3	43%	7	2	28.57%	4	1	25%	3	1	33.33%	3	0	0%
	p2	67	18	26.87%	40	6	15%	20	6	30.00%	20	6	30%	19	6	0%	7	2	28.57%	13	2	15.38%
	p3	99	31	31.31%	16	5	31.25%	37	8	21.62%	37	8	21.62%	33	6	18%	11	1	9.09%	16	3	18.75%
	p4	57	20	35.09%	24	3	12.5%	18	8	44%	18	5	27.78%	23	4	17.39%	6	1	16.67%	15	3	20%
p5	20	1	5%	2	0	0%	2	0	0%	2	0	0%	0	0	0%	2	0	0%	0	4	0%	
Metatarsal	total	167	36	21.56%	8	0	0%	72	18	25%	47	22	46.81%	76	36	47.37%	39	14	35.90%	30	17	56.67%
	p1	23	2	8.7%	1	0	0%	2	0	0%	2	0	0%	3	0	0%	0	0	0%	1	0	0%
	p2	40	11	27.5%	2	0	0%	5	2	40%	5	1	20%	21	4	19.05%	4	0	0%	6	2	33.33%
	p3	92	14	15.22%	2	0	0%	18	2	11.11%	18	3	16.67%	33	9	27.27%	10	0	0%	15	3	20%
	p4	33	8	24.24%	0	0	0%	16	2	12.50%	16	5	31.25%	25	4	16.00%	7	1	14%	3	1	33.33%
p5	10	0	0%	0	0	0%	0	0	0%	0	0	0%	2	0	0%	1	0	0%	0	0	0%	
Metapodial	total	68	2	2.94%	6	1	16.7%	25	3	12%	25	13	52%	13	5	38.46%	9	2	22.22%	21	2	9.52%
	p1	3	1	33.33%	1	0	0%	1	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
	p2	0	0	0%	2	1	50%	1	0	0%	0	0	0%	1	0	0%	0	0	0%	0	0	0%
	p3	13	0	0%	2	0	0%	8	0	0%	7	3	42.86%	1	0	0%	2	0	0%	8	0	0%
	p4	3	0	0%	1	0	0%	5	1	20%	8	2	25%	1	0	0%	1	0	0%	1	0	0%
p5	4	0	0%	2	0	0%	1	0	0%	0	0	0%	0	0	0%	1	0	0%	4	0	0%	
Total		742	186	25.07%	203	76	37.44%	367	112	30.52%	258	140	54.26%	303	136	44.88%	138	56	40.58%	176	69	39.20%

Supplementary data 6. A- MCA of full data, BOL: Bolomor, TD10: Grand Dolina TD10-1, RT: Riparo Tagliente, AM: Abri du Maras, SM: Saint-Marcel and Exp: Experiment; Int: Intuitivity (Vettese et al. in prep.), Moc: Moclan and Dominguez-Rodrigo 2018, Ham: Hammerstone on anvil and Batt: by batting (Blasco et al. 2013). NI: without impact and I: with impact B- Contributions variables on the first and second dimensions; C- Correlation of the variables on the two first dimensions; D-Cos² of the variables.



Supplementary data 7. MCA of all levels and element taking into account only the portion and side with percussion marks according to illustrative variables. A- Bone Element; B- Sites; C- Levels.



Annexes 5

Daujeard, C., Vettese, D., Britton, K., Béarez, P., Boulbes, N., Crégut-Bonnoure, E., & Allué, E. (2019). Neanderthal selective hunting of reindeer? The case study of Abri du Maras (south-eastern France). *Archaeological and Anthropological Sciences*, 11(3), 985-1011.



Neanderthal selective hunting of reindeer? The case study of Abri du Maras (south-eastern France)

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Abstract

Monospecific exploitation of reindeer by Neanderthals is a common behaviour in the Upper Pleistocene of Western Europe. However, reindeer-dominated assemblages have largely been reported from regions of northern Germany and south-western France, with few examples noted in south-eastern France, where faunal assemblages yield most of the time a variety of other large ungulates such as red deer, horse and diverse bovids. Here, we present multi-strand (bio- and eco-) archaeological datasets from the site of Abri du Maras (level 4.1), situated at the mouth of the Ardèche and Rhône rivers, a new example of a reindeer-dominated Neanderthal site in south-eastern France. Dated to the beginning of the MIS 3, the zooarchaeological assemblage is dominated by reindeer (88% of the NISP, representing 16 individuals) but also includes horse, bison, giant deer (*Megaloceros giganteus*), red deer, ibex and lagomorphs. The combination of zooarchaeological, cementochronological and tooth microwear analyses evidence a single species-dominated spectrum, with catastrophic mortality and repeated autumnal deaths. This integrated approach provides an extensive picture of human subsistence behaviour, pointing to short-term hunting episodes of reindeer herds in an exceptional context of a quasi-exclusive Neanderthal accumulation. The high number of individuals and selective butchery may correspond with a cooperative and planned mass hunting strategy. The multidisciplinary approach undertaken here also incorporating paleontological, charcoal, ecological and isotopic analyses places the archaeological and zooarchaeological data within a broader regional palaeoenvironmental framework, providing valuable landscape-contextual information. The zooarchaeological data suggest a subsistence behaviour different from other Neanderthal reindeer-dominated assemblages often connected with specialised butchery or hunting sites.

Keywords Neanderthal · Subsistence · Seasonality · Monospecific faunal assemblages · Reindeer predation · Mass procurement

Introduction

The hunting abilities of Neanderthals are now well documented, not least due to the many debates at the end of the twentieth century concerning the recognition of human versus carnivore faunal accumulations and the question of hunting versus scavenging in Middle Palaeolithic occupations (e.g. Binford 1981, 1988; Chase 1986; Stiner 1994; Marean

1998; Patou-Mathis 1997). More recently, other important advances have been made in archaeological research and associated fields, which not only demonstrate the proficiency of Neanderthal (and their predecessors) hunting, and have also revealed further similarities, and a far closer relationship, to modern humans than previously thought (Green et al. 2010; Fu et al. 2015). The decreasing gap in the perceived biological distance between modern humans and Neanderthals is mirrored by archaeological research, as the behavioural juxtapositioning of ‘Humans vs. Neanderthals’ is increasingly called into question. In the field of subsistence and game exploitation, new evidence of hunting weapons discovered at Schöningen (Thieme 1997; Schoch et al. 2015), combined with many archaeozoological studies (e.g. Gaudzinski 1996; Patou-Mathis 2000), have highlighted specialised Neanderthal predation of medium- and large-

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sized ungulates, and archaeozoological and isotopic studies have evidenced targeted interception hunting (e.g. Gaudzinski and Roebroeks 2000; Britton et al. 2011; Julien et al. 2015; Kuitens et al. 2015; Rivals et al. 2015b).

Single-taxa assemblages are significant as the tactic of specialised and mass hunting involves planning and collaborative behaviours. This is particularly the case when assemblages are the result of focused temporally constrained hunting activities, where resources are seasonally restricted (e.g. due to their migratory behaviour) or where the condition of prey-species is highly seasonally varied (for example, in reindeer). Often species targeted are gregarious and would have been intercepted by humans at places attracting the aggregation of many individuals, for example, at water sources, or more seasonally at calving grounds, during the rut, or along migratory corridors. Monospecific assemblages that are rapidly accumulated such as single mortality events are also significant in that they suggest mass food procurement and through this imply the planning of carcasses processing and the storage and transport of meat and marrow for deferred consumption (David and Enloe 1993; Costamagno et al. 2006; Gaudzinski-Windheuser and Kindler 2012; Rendu et al. 2012). In this sense, monospecific assemblages imply advanced planning and cooperative hunting behaviours and an in-depth knowledge of prey and landscape.

Monospecific faunal assemblages appear from MIS 9 to 7 with pre-Neanderthals and become more common from the beginning of the Last Glacial period to the end of the Middle Palaeolithic (Gaudzinski 1996; Patou-Mathis 2000; Gaudzinski-Windheuser 2006; Gaudzinski-Windheuser and Kindler 2012), without any specific increase during the Upper Palaeolithic (Grayson and Delpech 2002, 2003; Kitagawa et al. 2012). Indeed, many pre-Neanderthal and Neanderthal sites in Europe and in the Middle East highlight specialised hunting for a wide variety of middle-sized or large-sized ungulates: reindeer at Salzgitter-Lebenstedt, Les Pradelles, Jonzac and Combte-Grenal-“upper N2” (Gaudzinski and Roebroeks 2000; Costamagno et al. 2006; Airvaux 2004; Niven et al. 2012; Discamps and Faivre 2017); camel at Umm El Tlel (Boëda et al. 2001); aurochs and/or bison at La Borde, Mauran, Wallertheim and Il’skaja I (Jaubert et al. 1990; Farizy et al. 1994; Gaudzinski 1995; Hoffecker et al. 1991); red deer at Saint-Marcel and Le Lazaret (Daujeard 2007, 2008; Valensi et al. 2013); horse at Orgnac 3, Zwolen, Kabazi II and Starosele (Gautier 1989; Patou-Mathis 1999; Burke 2000, 2006; Moncel et al. 2012); or small bovids, ibex or chamois at Scladina (Patou-Mathis 1998), Baume des Peyrards (Daujeard 2008), Zafarraya (Caparrós et al. 2012) and in the numerous Middle Palaeolithic sites of the Pyrenean, Alpine, Cantabrian and Caucasus mountains (e.g. Patou-Mathis 2000; Yravedra and Cobo-Sánchez 2015).

Monospecific assemblages at Neanderthal sites often share common characteristics, for example, accumulation via regular short events, the predominance of remains of a single species (and many individuals) associated with lithic artefacts and cut marks, catastrophic mortality profiles and selective transport of carcass portions from the kill site to the base camp (Gaudzinski-Windheuser 2006; Costamagno et al. 2006; Gaudzinski-Windheuser and Kindler 2012; Rendu et al. 2012). In light of cross-site similarities, ungulate mass procurement hypothesis is often confirmed or refuted through a similar compilation of multiple zooarchaeological lines of evidence, e.g. threshold number of prey bones, mortality caused by humans, single depositional episode and single mortality event (Lubinski 2013).

However, the assessment of monospecific (and other) faunal assemblages, and their interpretation, is blighted by the problem of equifinality in accumulations resulting from combined carnivore and anthropogenic action (Rogers 2000; Lyman 2004). Despite huge progress in the recognition of the various agents of accumulation over the last decades (mainly thanks to archaeological and experimental data on bone surface modifications; age and skeletal profiles or faunal spectra: Cruz-Urbe 1991; Blumenshine et al. 1996; Pickering 2002; Guadelli 2008; etc.), exclusively human accumulations still represent the best contexts to study human behaviours. Unfortunately, such sites remain rare in the Middle Palaeolithic but are vital for confidently inferring past behaviours.

Here, we present new zooarchaeological, archaeological, paleontological and isotopic data from the Middle Palaeolithic site of Abri du Maras, Ardèche, in Southeast France. The site was first excavated by R. Gilles and J. Combier during the second half of the twentieth century and research was resumed at the site in 2010 by one of the authors (M.-H. Moncel). Abri du Maras is now the focus of a major multidisciplinary archaeological investigation. This vast rock shelter is situated along the right bank of the Middle Rhône Valley, at the confluence with the Ardèche River and features several well-preserved levels of occupation dated to the first half of the Last Glacial period (MIS 4–3) (Moncel and Michel 2000; Richard et al. 2015). Abri du Maras comprises an extensive assemblage of anthropogenically modified animal bones associated with Middle Palaeolithic lithic artefacts, with very few carnivore remains and little evidence of carnivore activity. Due to the excellent spatial preservation of level 4.1, which is dominated by reindeer, and the likelihood that Neanderthals were practically the sole accumulators, this phase of the site is ideal for furthering our understanding of Middle Palaeolithic monospecific and mass faunal assemblages, and therefore, for elucidating Neanderthal landscape use, hunting practices and social behaviours.

Thus, the main objective of this paper is to attempt to reply to this question: ‘Did Neanderthals selectively hunted reindeer at

Abri du Maras level 4.1?', and that thanks to the most accurate chronological (both biostratigraphy and absolute datings), palaeoenvironmental (faunal, isotopic and dental microwear analyses) and taphonomical features of the human occupations.

Abri du Maras

Geographical setting

The site of Abri du Maras (170 m a.s.l.) is situated on the right bank of the Middle Rhône Valley, in a small dry valley of the Ardèche River, at the outer edge of the gorges (Fig. 1). It is perched 70 m above the river and is all that remains of a huge, former south-east facing rock shelter. This rock shelter is the relict of successive phases of tectonic activity, dissolution and erosion processes that contributed to exposing and altering a pre-Quaternary karst network. The presence of large limestone slabs throughout the sequence evidences the vast expansion of the shelter at the time of occupation and also to its final collapse soon after the last occupation (Debard 1988; Moncel et al. 2010, 2015).

The Rhône Valley comprises notable archaeological and topographical features: a vast corridor linking the North of Europe to the Mediterranean zone and a key position between two mountainous regions—the Massif Central to the west and the Alpine foothills to the east. Many East-West tributaries on the right bank of the Rhône River connect the Rhône Valley to the plateaus of the Massif Central. In this region, previous studies of Neanderthal subsistence suggested a probable seasonal model, based on the presence of sites with different occupation types. Evidence of settlement in caves and rock shelters clustered around the Ardèche gorges results from the seasonal activities of larger groups, focusing on monospecific prey, while the occasional bivouac occupations of other sites are more likely to represent opportunistic faunal exploitation alternating, for example, with carnivore visits (Daujeard 2008; Daujeard and Moncel 2010; Moncel and Daujeard 2012; Daujeard et al. 2012).

Stratigraphy and dating

The first archaeological investigations at Abri du Maras revealed a stratigraphic sequence of about 3 m including eight levels with Middle Palaeolithic deposits. This site was renowned in the past for its Middle Palaeolithic (MP) deposit with a Levallois laminar debitage (level 1) (Gilles 1950; Combier 1967; Debard 1988; Moncel et al. 1994). The excavations are conducted with classical methodologies, using a square meter grid and plotting each object with a total station. A SIG database provides the spatial distribution (vertical and horizontal) information. Sediments are systematically

checked by first dry screening then wet screening for micro-fauna, micro-flakes and shells. The new excavation only concerns the middle and lower parts of the sequence, from previously assigned levels 4 to 8. The stratigraphic unit 5 (levels 8–6 of earlier excavations) is at present the oldest currently known unit and lies abruptly on the erosional contact of the limestone substratum at the back of the shelter. The overlying unit 4 (this study has been extensively exposed across the rock shelter and consists of a silt and sandy-silty sedimentary accumulation (0.5 to 1 m thick). The coarse fraction results from frost shattering the walls of the rock shelter. The fine fraction can be assigned to loess-like deposits of aeolian origin (Antoine 2002), on the basis of sedimentological data (Fig. S1a–b). The mineralogy (Nowak 2013; Puaud et al. 2015) indicates that the deposit appears to have mostly originated from the wind erosion of the fluvio-glacial terraces of the Middle Rhône valley during the cold and dry conditions of MIS 3. Micromorphological features (Fig. S1c) show that the entire unit 4 appears to have been affected by moderate pedological evolution, mostly expressed by earthworm bioturbation and the biogenic redistribution of calcium carbonate (Brochier 1976; Jaillard et al. 1991; Canti 1998; Kooistra and Pulleman 2010).

Unit 4 contains in its upper part two archaeological levels, 4.2 and 4.1 (Fig. 2). The excavation showed that these two levels (previously 5 and 4) correspond respectively to two well-preserved human occupation phases marked by abundant artefacts with scant traces of combustion and occasional diffuse ash lenses. Unit 4 is currently excavated over an area of more than 50 m², in the front of the remaining shelter (Moncel et al. 2014). Finally, only scattered and rare artefacts have been encountered in the overlying units (3, 2, and 1), which contrast with unit 4 by their coarse texture and the abundance of large blocks.

U-Th dating applied to bones from the top of unit 5/bottom of unit 4 yielded ages of 72 ± 3, 87 ± 5, 89 ± 4, and 91 ± 4 ka (Moncel et al. 1994; Moncel and Michel 2000). New preliminary ESR/U-Th dating of ungulate teeth confirmed the chronology of unit 5 (90 ± 9 ka) but gave more recent ages for unit 4, attributed to MIS 3. Level 4.1 (upper part of unit 4) thus dates to between 40 ± 3 and 46 ± 3 ka ($n = 2$) (also MIS 3), while samples from level 4.2 provided ages ranging from 42 ± 3 to 55 ± 2 ka ($n = 3$) (Richard et al. 2015).

Archaeology and environment

The close association of archaeological materials with coarse fraction issued from the pedogenic alteration of the limestone cliff together with collapsed limestone slabs in the two occupation levels (levels 4.1 and 4.2) of unit 4 enables us to establish strict synchrony between human presence and climatic conditions characterised by seasonal moisture and mild temperatures. In contrast, the fine silt texture typical of aeolian

Fig. 1 Location of the Abri du Maras. Site situation on the edges of the Rhône valley in the context of the south-eastern Middle Palaeolithic (Map adapted from Tessier, in Daujeard et al., 2011)



F. Tessier del. 2011

dust, the weak effect of pedogenesis and the lack of coarse limestone fraction in the sterile level deposited between levels 4.1 and 4.2 indicate that the site was not occupied when the climate was colder and drier. Microfauna, charcoal and pollen are very rare at the site due to poor preservation. Previous faunal studies highlighted the presence of temperate species

such as red deer, roe deer and wild boar in unit 5, whereas cold and open environment species such as reindeer, horse and bison are more common in unit 4 and in the overlying units. The varied faunal spectrum previously obtained for the unit 4 is composed, in order of abundance, of *Rangifer tarandus*, *Equus ferus* cf. *germanicus*, *Cervus elaphus*, *Bison priscus*,

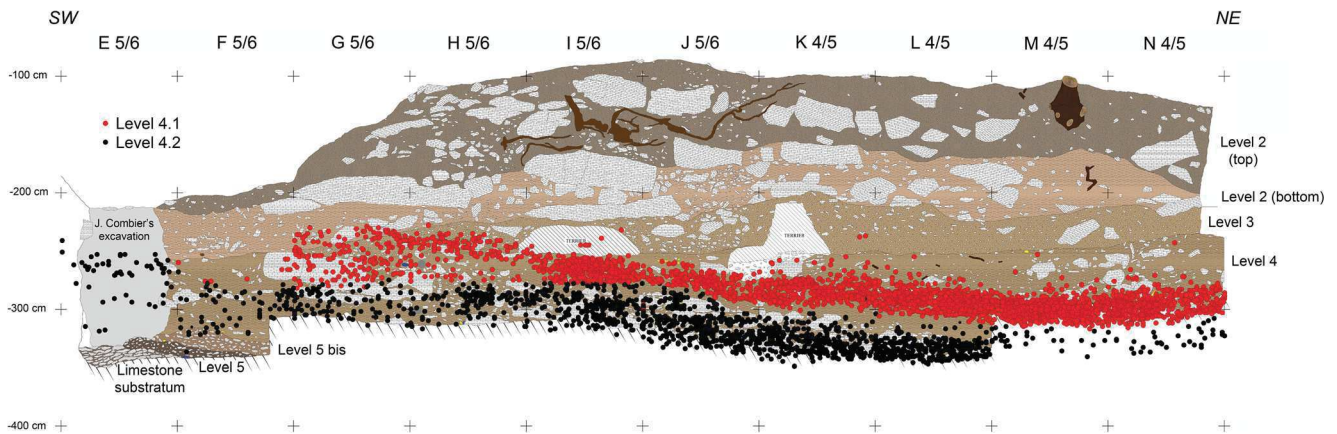


Fig. 2 GIS projections of the faunal and lithic items on the stratigraphic profile: band 6 in unit 4 (Figure by R. Gallotti and S. Puaud)

Capra ibex, *Equus hydruntinus* and *Megaloceros giganteus*. All along the sequence, faunal remains are mainly related to anthropogenic activities and carnivore marks are scarce (Moncel et al. 1994; Daujeard 2008; Daujeard and Moncel 2010; Moncel et al. 2015).

In this paper, we focus on level 4.1, the uppermost occupation unit 4, due to the lack of carnivore action, remarkable spatial preservation with short object displacements, technological behaviour based on similar strategies suggesting occupations close in time and the presence of ash lenses. Level 4.1 has been exposed over a surface of 34 m². The excavation revealed a dense accumulation of archaeological remains reaching a total thickness of 20 cm. However, the clayey-sandy silt sedimentary matrix of level 4.1 is homogenous throughout and does not display any significant change in colour, structure or texture, in close association with the occurrence of the archaeological remains. Based on the lack of field evidence, it was presumed that archaeological level 4.1 did not present well-preserved living floors. However, the meticulous excavation of this level revealed the scattered occurrence of fire traces, mostly represented by poorly preserved millimetre-sized charcoal fragments which are finely incorporated in the matrix. Burnt flint and burnt bone also provide evidence of the use of fire and are dispersed over the archaeological level. In addition, occasional centimetre-sized lenses formed of dark-brown to brownish-grey silty clay, consisting of densely packed biogenic aggregates with high quantities of fine charcoal, ash micro-aggregates, burnt bones and polymer films occur throughout level 4.1. Based on their field facies and the abundance of combustion residues, the lenses have been assumed to be relicts of fire-related activities. They are all located at a same deepness, suggesting a main phase of occupation. An important number of faunal and lithic refits have been identified in level 4.1 (Fig. 3). In the case of the faunal assemblage, the total number of refits is 65 ($n = 44$ on fresh and

21 on dry bones) connecting 148 items. The longest refit is formed by eight elements ($n = 1$) but the majority have only two elements ($n = 51$). In addition, we also identified 22 faunal anatomical connections (in situ and during the post-excavation faunal analysis), grouping 68 bones. There are also 10 lithic refits comprising a total of 20 pieces (mainly flakes and all formed by two elements). The raw materials involved are flint ($n = 7$) and quartz ($n = 3$). The connection lines are mainly related to knapping sequences ($n = 6$), although some are the result of fractures (during knapping $n = 2$ and post-depositional $n = 2$). The fact that faunal and lithic connections lines are short (mean of 1.5 m) and some of the connected items are small (≤ 1.5 mm) corroborates the low level of disturbance of the archaeological assemblage from level 4.1.

The lithic material in level 4.1 totals 1844 items. The density is 135 pieces/m² and 54/m³. Lithic analysis, undertaken



Fig. 3 Two refitted tibia fragments of a large cervid: *Cervus* or *Megaloceros* (level 4.1, J6-85 and J6-85/1) (Photos by D. Vettesse and M.G. Chacon)

by several of the authors, revealed that the technical strategies applied mainly to flint and secondarily to other stones (quartz, quartzite and granite) indicate the fragmentation of reduction processes into local and semi-local perimeters around the site (Moncel et al. 2014). The main core technology is Levallois, generally on cortical flint cores on flakes. Flint flakes, blades and points are the main components of the series and the technological aims of the debitage. The largest flint flakes, Levallois blades (cortical or not) and Levallois points were produced elsewhere, to the north and south of the site (up to 20–30 km), according to the geological study, and then brought to the shelter. Flake tools are very rare (3%) and never modified the shape of the pieces. Levallois products were never retouched. We may mention one Quina scraper made on a thick and large flint flake. Evidence of impact fractures suggests that some points, brought to or prepared on the site, could have been used as projectile tips (Hardy et al. 2013). The lithics attest to the management of local and semi-local stones in a perimeter of 30 km around the site (possibly more due to some unidentified flint) and an anticipation of domestic needs. Imported artefacts and artefacts made on the site were used for the same range of activities and materials (butchery, plant and woodworking) (Moncel et al. 2014). At Abri du Maras (level 4.1), Neanderthals exploited a wide range of resources including large mammals, fish, ducks, raptors, rabbits, mushrooms, plants and wood. Twisted fibres on stone tools provide possible evidence of making string or cordage (Hardy et al. 2013).

Material and methods

The faunal material included in this study comes exclusively from archaeological find level 4.1 from Abri du Maras. The analysis of the faunal assemblage features a range of scientific approaches and methodologies including taphonomic and zooarchaeological analysis in order to explore the species present, age-at-death (when possible), and infer anthropogenic modifications and other taphonomic features; cementochronology to infer season-of-death; stable isotope and dental microwear analysis to explore the niche feeding behaviours of the exploited species, and palaeoenvironmental proxies in order to gain better insight into the MIS 3 ecosystem surrounding Abri du Maras.

Taphonomy and zooarchaeology

The taphonomic and zooarchaeological studies concern all the faunal remains from level 4.1 since the 2006 excavations. We report the total number of skeletal remains (NR), the number of taxonomically and anatomically identified specimens (NISPt and NISPa), the minimum number of elements (MNE) and the minimum number of individuals (MNI)

(Binford 1984; Lyman 1994). The taxonomical and anatomical identifications were made thanks to the French National Museum and Institut de Paléontologie Humaine comparison collections and by referring to the book of Barone (1999) for the anatomical nomenclature. In level 4.1, small and large mammals represent 11,123 remains including indeterminate remains (Table 1). The number of recorded remains is 2919 and 1347 remains have been identified to the anatomical level and 1170 to the species level. Fish remains account for 167 bone elements, birds are represented by two remains and we recorded five micromammal anatomical elements. Systematic sieving was undertaken during the excavations and the scarcity of microfauna is mainly due to poor bone preservation (see below).

In order to discuss the meat procurement strategy (hunting or scavenging), selective carcass transport to the site and differential bone preservation, we used the percentage of Minimal Animal Unit (MAU, Binford 1984), the Food Utility Index (FUI) (Metcalfé and Jones 1988; Lyman 1994), the volume of the marrow cavity (Binford 1978, in Jones and Metcalfé 1988) and the bone bulk density (Lyman 1984; Lam et al. 1999). Carcasses were divided in seven main anatomical parts: head (skull, mandibles, isolated teeth excepted); axial elements (vertebrae, ribs, sternum); forequarters (scapula, humerus, radio-ulna); forefoot (carpal, metacarpal); hindquarters (pelvis, sacrum, femur, tibia, patella); hindfoot (tarsal, metatarsal); and indeterminate foot (phalanges, sesamoids, metapodials) (after Wilson 1989, modified).

Seasonality and ontogenic age-at-death of prey specimens is based on dental eruption and replacement patterns (for deciduous teeth concerning the season of death) and then on tooth wear (wear stages for reindeer: cf. Bouchud 1966 and Miller 1974; for red deer and by analogy giant deer: Riglet 1977; for bison: Brugal and David 1993; and for horses: Guadelli 1998; Forsten and Moigne 1998 or Bignon 2003). Five main age groups were established: juveniles (with deciduous teeth), young adults (with erupted P4 and M3), prime age adults (with moderately worn P4 and M3), old adults (with heavily worn P4 and M3) and senile (almost no enamel remains on P4 and M3) (Grant 1982; Klein and Cruz-Urbe 1984; Forsten and Moigne 1998). For reindeer, these five age classes represent nearly the same lifetime with juveniles

Table 1 Counts of the faunal assemblage and bone preservation indexes

	NTR	Total Recorded	NISPa	Isolated teeth	Illegible bone remains
NR	11,123	2919	1347	231	902
%	100.0%	26.2%	12.1%	17.1%	33.2%

NTR number of total remains, *NISPa* number of anatomically identified specimen

ranging from 0 to 2.5 years old; young adults, 2.5 to 5; prime age adults, 5 to 7.5; old adults, 7.5 to 10; and senile, up to 10 years old. In order to use ternary diagrams established by Stiner (1990), the three age categories were corrected—juveniles (<2.5), adults (2.5 to 10) and old individuals (>10)—according to their relative lifespans. For larger ungulates, such as bison and horse, the adult category begins later, with the loss of the D4 and the eruption of the P4 and M3, at about 40–50 months old.

For comparative purposes for large mammal representation, richness and diversity indexes were calculated (Simpson 1949; Magurran 1988; Grayson and Delpech 2002; Valensi et al. 2013): (1) the taxonomic richness: $R = S - 1/\ln$ MNI (with S = number of species and MNI = total minimum number of individuals); (2) the Simpson index: $D = \sum ni[ni - 1]/N[N - 1]$ (with ni = the number of specimens for each species and N = the total number of specimens); (3) the Shannon diversity: $H = - \sum [(MNI_{sp}/MNI_{tot}) \log_2(MNI_{sp}/MNI_{tot})]$ (with MNI_{sp} = minimum number of individuals for each taxon and MNI_{tot} = total minimum number of individuals) or $H = - \sum [(NISP_{sp}/NISP_{tot}) \log_2(NISP_{sp}/NISP_{tot})]$ (with $NISP_{sp}$ = number of identified specimens for each taxon and $NISP_{tot}$ = total number of identified specimens); and (4) the Equitability index or Evenness is obtained by the Shannon index/ \ln (n taxa).

For the taphonomic analysis, the dimensions (length, breadth and thickness) and modification data were recorded for all the recorded and identified specimens. Indeterminate fragments less than 25 mm were only used for counts, fragmentation studies (type and size classes) and carbonization analyses. The identification of the type of breakage (green, dry or recent bone fractures) was made based on the fracture colour, shape, feature and angle and associated marks (Villa and Mahieu 1991). The recorded percussion marks are (Blumenschine and Selvaggio 1988; Capaldo and Blumenschine 1994; Blasco et al. 2013) medullary or cortical percussion notches (negative flake scars); impact flakes (positive flake scars); percussion pits; adhering flakes; and peeling and micro-notches (Vettese 2014, Vettese et al. 2017). The shaft fragments were differentiated by size and circumference classes (cf. Villa and Mahieu 1991). For indeterminate fragments, two main size categories were established, adapted to the ungulates present in our sample: (1) medium-sized ungulates with a weight between 50 and 300 kg (red deer, reindeer and ibex) and (2) large-sized ungulates with a weight between 300 and 1000 kg (large bovids, horse and giant deer).

All bone surfaces were visually assessed, with some studied further using a stereomicroscope (Leica S8 APO, magnification $\times 10$ –80) in order to distinguish surface modifications, and photographed. Type and location of modifications were recorded, including those made by rodents, carnivores or hominins as well as climatic and edaphic modifications (including cracking, desquamation, polish, concretion, root

marking, chemical corrosion and oxides coloration). The identification of these main taphonomical modifications was based on the criteria defined by Behrensmeyer (1978), Binford (1981), Lyman (1994) and Fisher (1995). The undecipherable remains were not included in the percentages. Trampling marks were distinguished from butchering marks using the works of Binford (1981), Shipman and Rose (1983, 1984), Behrensmeyer et al. (1986), Olsen and Shipman (1988), Blasco et al. (2008) and Domínguez-Rodrigo et al. (2009)). The location and morphology of the latter may indicate the related butchering activity, including evisceration, skinning, dismemberment; disarticulation, periosteum removal, cutting tendons and defleshing (Binford 1981; Nilssen 2000; Pobiner et al. 2008; Costamagno and David 2009). Following Binford (1981), Haynes (1983) and Campmas and Beauval (2008), carnivore marks were classified as follows: pits, punctures, scores, notches or corrosion by gastric acids. Damage due to burning was recorded using the different colour stages described by Stiner et al. (1995) (Table S1). In addition, burnt elements were categorised according to their length and intrinsic characteristics: spongy, compact or dental portions.

In order to assess the season-of-death in addition to the dental eruption periods, we tested cementochronology. Multiple teeth from nine deer including one giant deer and eight reindeer from level 4.1 were selected as these appeared to the naked eye to have intact outer dental cementum. The methodology employed here for dental cementum growth mark analysis (cementochronology) of the cervid teeth follows the protocol described in Pike-Tay (1995) and Pike-Tay and Cosgrove (2002), which built upon the methodological contributions of Pike-Tay (1991), Lieberman et al. (1990) and Burke (1993), including (1) the preparation and use of radial ‘dry’ thin sections (ca. 30 μ) taken at the mesial-distal midline of the tooth, (2) the use of polarised transmitted light (common mag. = $\times 40$, $\times 100$, $\times 250$) and (3) for taking measurements of consecutive growth zone widths at two or three cementum transects per tooth in the areas of acellular cementum near the tooth cervix (root/enamel junction) where, on cervid and bovid teeth, the apposition of growth increments is most regular.

Other palaeoenvironmental proxies

Isotopic studies

As part of a broader multi-isotope study incorporating faunal bones and teeth from multiple archaeological find levels at Abri du Maras, a small number of bones ($n = 9$) from three different taxa (*Equus*, *Megaloceros*, *Rangifer*) were selected from level 4.1 for collagen extraction and carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotope analysis. The stable isotope analysis of bone collagen is not only useful in archaeological studies to infer human palaeodiet but can also provide information about

the broader environment and also about niche partitioning and feeding behaviours of different herbivore taxa, even within purely-C3 plant communities (e.g. Bocherens 2003; Feranec 2007), for example, the consumption of lichens, which exhibit higher $\delta^{13}\text{C}$ values than other terrestrial C3 plants (Ben-David et al. 2001; Drucker et al. 2001, 2012) or feeding in forested environments, which typically have more negative $\delta^{13}\text{C}$ values due to the ‘canopy effect’ (Cerling et al. 2004; Noe-Nygaard et al. 2005). Although they are on the same trophic level, absolute $\delta^{15}\text{N}$ values of herbivore tissues depend on a number of factors and in particular on the varying ^{15}N levels of the plants they consume (and ultimately the soils) at the base of the food chain. For a recent review of the factors influencing nitrogen isotope ratios in plants, including plant physiology, see Szpak (2014). Therefore, given that local variation in soil and plant $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ isotope composition is reflected in local herbivores, the stable isotope analysis of animal bone collagen can be used to investigate resource partitioning and underlying isotopic variations in ancient ecosystems (Britton et al. 2012). Moreover, the absolute $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ determined in herbivore bone collagen at archaeological sites can also be utilised to infer broad palaeoclimatic conditions (e.g. Richards and Hedges 2003; Stevens and Hedges 2004; Stevens et al. 2008). This is due to the relationship between ‘baseline’ ecosystem $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of soils and plants and changing diachronic environmental factors such as aridity/moisture and temperature (e.g. Heaton et al. 1986; Schwarcz et al. 1999; van Klinken et al. 2000). In this way, overall dataset values and trends (between the different herbivore species) can shed light on the palaeoenvironmental and palaeoecological conditions at Abri du Maras.

Herbivore bone ($\approx 1\text{--}2\text{ g}$) was sampled for collagen extraction using rotary stainless steel cutting implements and cleaned using air abrasion. Collagen was extracted using the Longin method (1971), with modifications based on the recommendations of Collins and Galley (1998) and with the addition of an ultrafiltration step (Brown et al. 1988), as described in Britton et al. (2012). Collagen samples were analysed (in duplicate) for stable carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotope ratios at the Department of Human Evolution, Max Planck Institute for Evolutionary Anthropology (MPI-EVA, Leipzig, Germany), on a Delta XP mass spectrometer coupled to a Flash EA 2112 elemental analyser.

Dental microwear analysis

In this study, we selected all teeth available from the Abri du Maras level 4.1. A total of 17 teeth (both upper and lower molars) were sampled, 14 of *R. tarandus* and 3 of *E. ferus*.

Microwear features of dental enamel were examined using a stereomicroscope on high-resolution epoxy casts of teeth following the cleansing, moulding, casting and examination protocol developed by Solounias and Semprebon (2002) and

Semprebon et al. (2004). In short, the occlusal surface of each specimen was cleaned using acetone and then 96% alcohol. The surface was moulded using high-resolution silicone (vinylpolysiloxane) and casts were created using clear epoxy resin. All specimens moulded were carefully screened under the stereomicroscope. Those with badly preserved enamel or taphonomic defects (features with unusual morphology and size or fresh features made during the collecting process or during storage) were removed from the analysis following King et al. (1999). After discarding unsuitable material, the sample was significantly reduced to eight teeth of *R. tarandus* and two of *E. ferus*.

Casts were observed under incident light with a Zeiss Stemi 2000C stereomicroscope at $\times 35$ magnification, using the refractive properties of the transparent cast to reveal microfeatures on the enamel. Microwear scars (i.e. elongated scratches and rounded pits) were quantified on the paracone of the upper teeth in a square area of 0.16 mm^2 using an ocular reticule. We used the classification of features defined by Solounias and Semprebon (2002) and Semprebon et al. (2004) as follows: pits (small and large pits, puncture pits), scratches (fine, coarse, hypercoarse) and gouges. Pits are microwear scars that are circular or sub-circular in outline and thus have approximately similar widths and lengths, while scratches are elongated microfeatures that are not merely longer than they are wide but have straight, parallel sides. Large pits are deeper, generally at least about twice the diameter of small pits, and often have less regular outlines than do small pits. Gouges are features which have ragged, irregular edges and are much larger and deeper than large pits. Cross scratches are oriented somewhat perpendicularly to the majority of scratches observed on tooth enamel. In addition, scratch textures were assessed as being either fine, coarse or a mixture per tooth surface. The scratch width score (SWS) is obtained by giving a score of ‘0’ to teeth with predominantly fine scratches per tooth surface, ‘1’ to those with a mixture of fine and coarse types of textures and ‘2’ to those with predominantly coarse scratches (Rivals et al. 2007). Individual scores for a sample were then averaged to get the SWS.

The results were compared with a database constructed from extant ungulate taxa (Solounias and Semprebon 2002). Using average scratch and pit data, it is possible to discriminate between the dietary categories of browser (i.e. eating woody and non-woody dicotyledonous plants) versus grazer (i.e. eating grass). Mixed feeding ungulates can best be separated from browsers or grazers by calculating the percentage of individuals in a population with scratch numbers that fall between 0 and 17 scratches in the 0.16-mm^2 area (0–17%) (Semprebon and Rivals 2007). Thus, for extant ungulates, the percentages of individuals in the low-scratch range are generally as follows: grazers with 0.0–22.2%, mixed feeders with 20.9–70.0% and leaf browsers with 72.7–100.0% (Semprebon and Rivals 2007).

Table 2 Number and percentage of recorded bone remains (NR = 2718) with green, dry, frozen or indeterminate bone breakage

Green			Dry		Gelifracsts		Indeterminate	
NR	NR	%	NR	%	NR	%	NR	%
2718	2003	73.69%	950	34.95%	58	2.13	483	17.77%

Finally, following Rivals et al. (2015a), two measurements of variability of scratch density, namely the standard deviation (SD) and the coefficient of variation (CV), are used to estimate the relative duration and seasonality of the mortality event(s) of the reindeer from Abri du Maras level 4.1.

Results and data interpretation

Bone preservation

The identification index, defined as the number of anatomical identified remains compared to the total number of remains, is around 12%, which is low and mainly due to the high fragmentation of the fauna (Table 1 and Fig. S2). Indeed, the faunal assemblage is characterised by an important quantity of unidentified bone splinters and by a few isolated teeth (Table 1). Almost three-quarters of the recorded bone remains have one or several green bone fractures (Table 2). Fracture profiles are mainly curved/V-shaped along with oblique angles and smooth edges (Fig. 4). Post-depositional fragmentation due to sediment compaction or secondary frost action damaged more than one third of the recorded remains. Only five complete or almost complete long bones were recorded. They are all metapodials: one horse metacarpal (III), three reindeer metacarpals and one reindeer metatarsal. Shaft bone fragments are far more numerous than epiphyseal fragments (Fig. S3). The vast majority (89%) have been reduced to a C1 circumference and have a L1/L2 length (Fig. S4).

To evaluate the impact of bone preservation on the assemblage, we correlated bone density indexes with the %MAU for reindeer remains, which is the predominant species. The



Fig. 4 Photo of a reindeer metacarpal fragment. This fragment presents green bone fractures and a whole distal portion (level 4.1, J6-39) (Photo by C. Daujeard)

significantly positive correlation obtained between %MAU and bone density (with Spearman's $r_s = 0.65$, $df = 29$ and $t = 4.67$; $p < 0.001$) indicates strong differential destruction within the faunal assemblage. However, bone preservation is variable, depending on the excavated surface areas of the rock shelter. Some display an excellent degree of preservation and others show a high bone destruction index. The bone destruction index, calculated as the number of isolated teeth compared to the total number of anatomically identified remains, is around 17%, which is moderate (see Daujeard 2008 for regional comparisons), but this rate may also be due to a strategy of abandonment of the heads at the kill site (see below) (Table 1). The representation of the various long bone portions confirms the impact of differential bone destruction on the sample (Fig. S3). Indeed, the best represented extremities are those with greater bone density, i.e. metapodials, radius-ulna and distal humerus (see Lam et al. 1999). The good preservation of some articular portions can be explained by the almost complete lack of carnivorous action. Only 10 bone elements bear carnivore marks, which represents less than 1% of the recorded and decipherable remains. These are long bone articular portions of horse and reindeer and a few indeterminate remains. Besides that, there are also a very few remains (NR = 7, < 1%) with random striations on their surface which can be associated with trampling.

Remains with undecipherable surfaces are numerous, representing one third of the recorded remains (Table 1). They have been excluded from the cut mark or bone retoucher analyses in order to avoid biasing the calculation of the rates. This poor surface preservation is mainly due to root etching which is present on almost 90% of the recorded bone remains, with more than 50% being invasive on two-thirds of the surfaces (Table S2). Evidence of weathering is scant and concretions and polishing are practically inexistent. Black and orange colorations (oxides) are omnipresent but limited over bone surfaces (mostly stage 1).

Palaeoenvironments: the faunal, isotopic, tooth microwear and charcoal evidence

Among small and large mammal remains, 98.7% of the NISP are ungulates and 1.3% are lagomorphs. There are no carnivore remains. They include, in order of abundance (Table 3), reindeer (*R. tarandus*), horse (*Equus ferus* cf. *germanicus*), giant deer (*M. giganteus*), bison (*Bison priscus*), red deer (*C. elaphus*), ibex (*C. ibex*) and lagomorphs (*Oryctolagus cuniculus* and *Lepus* sp.). This diversity confirms previous studies of level 4, highlighting open landscapes and a cold and arid climate (Comber 1967; Moncel et al. 1994; Daujeard 2008; Daujeard and Moncel 2010; Moncel et al. 2015). With 1170 bone and teeth remains, reindeer is by far the most abundant species in level 4.1, representing 88% of the NISP and 55% of the MNI. The total MNI of the reindeer

Table 3 Large and small mammal spectrum for level 4.1

Taxa	NISP	%NISP	MNI	%MNI	Age class
<i>Equus ferus</i> cf. <i>germanicus</i>	75	6.4%	4	13.8%	1J, 1YA, 1PA, 1OA
Perissodactyla	75	6.4%	4	13.8%	
<i>Rangifer tarandus</i>	1030	88.0%	16	55.2%	7J, 2YA, 2 PA, 3OA, 2S
<i>Cervus elaphus</i>	6	0.5%	1	3.4%	–
<i>Megaloceros giganteus</i>	20	1.7%	2	6.9%	1OA
Cervidae indet.	11	0.9%			–
<i>Capra ibex</i>	2	0.2%	1	3.4%	–
Caprinae indet.	3	0.3%			–
<i>Bison priscus</i>	8	0.7%	2	6.9%	1J, 1YA
Artiodactyla	1080	92.3%	22	75.9%	
<i>Lepus</i> sp.	3	0.3%	2	6.9%	1J
<i>Oryctolagus cuniculus</i>	2	0.2%	1	3.4%	–
Leporidae indet.	10	0.9%			–
Lagomorpha	15	1.3%	3	10.3%	
Total NISP/MNI	1170	100.0%	29	100.0%	

NISP number of identified specimen, MNI minimal number of individuals, J juvenile, YA young adult, PA prime age adult, OA old adult, S senile

is estimated at 16 individuals. Horse is the second species, with 75 specimens and four individuals. The richness (2.08) and diversity indexes (Shannon indexes for MNI = 1.5 and NISP = 0.44; Simpson index = 0.81 and $1/D = 1.23$) and Evenness index for NISP = 0.21) are low, highlighting limited diversity regarding the type of species.

Cervids are the most abundant taxa in level 4.1 with reindeer, red deer and giant deer. Reindeer (*R. tarandus*) were affected by body size variation during the Pleistocene (Bouchud 1966; Delpech 1983; Weinstock 2000; Kuntz 2011), but the bone remains from Abri du Maras level 4.1 are mostly badly preserved and very fragmented and are therefore not suitable elements for a morphometric analysis. Antler preservation also prevents such analysis. Furthermore, the much better preserved teeth seem to be a too stable indicator for this purpose. Red deer remains are also scarce and do not allow for an appropriate discussion of *C. elaphus* status and its biochronological implications. Giant deer (*M. giganteus*) displays typical dental morphology with a thick cingulum, wide and high entostyle and strong styles and stylids on both upper and lower molars. Upper premolars are also characterised by a thick, sometimes crenulated cingulum. These elements are consistent with morphologies observed on other Upper Pleistocene specimens (Prat 1968; Lister 1994; Vislobokova 2012).

Only a few elements from horses from level 4.1 are suitable for paleontological and metric analysis. Nevertheless, they all belong to the chrono sub-species *E. ferus* cf. *germanicus*, present throughout unit 4. Another equid species is present in level 4.2, *E. hydruntinus*, which is only represented by an upper molar with a very similar morphology to that of the sub-species *E. hydruntinus davidi*. As it is very poorly represented

in the sequence, the absence of this most thermophilic species in level 4.1 does not appear significant. From a biochronological point of view, the *E. germanicus* and *E. hydruntinus davidi* association is consistent with the chronological attribution of unit 4 to MIS 3 (Guadelli 1987; Boulbes 2009). More precisely, the dimensions (length = 225.4 mm; breadth of the diaphysis = 38.9; robustness index = 172.6) of the only complete horse metacarpal present in the level 4.1 (L6–54) are close to those of other series from Tournal cave (B/D levels), Combe-Grenal or Pair-non-Pair, contemporaneous of the MIS 3 (Guadelli 1987; Magniez et al. 2017). High level of robustness of the diaphysis could be an indication of humid context (Magniez et al. 2017). The few dental elements of large bovids enable us to identify the large steppic bison *B. priscus*.

A number of fish bones, mostly vertebrae, scales and fragments, have been retrieved from the excavation of the squares H6, I6 and J6 (Table 4). Their preservation varies from bad to very good, but fragmentation is high. Out of a total number of 167 fish remains, 46 could be identified to at least the family level. Two families are present: cyprinids (NISP = 34) and percids (NISP = 12). Among the cyprinids, the chub (*Squalius cephalus*) has been identified on the basis of a pharyngeal bone and several vertebrae. Percids are only represented by typical ctenoid scales belonging to the European perch (*Perca fluviatilis*). Both species are currently common inhabitants of the Ardèche River. Chub size has been estimated through direct comparisons with modern specimens from the reference collection. Estimated body weights range between 550 and 850 g. In the absence of any fish predator at the site, as well as signs of chewing or digestion, the presence of these fish remains in level 4.1 may result from anthropogenic

Table 4 Fish remains from level 4.1

m ²	Family	Species	Element	NISP	MNI	Estimated weight (g)
H-6	Cyprinidae	Unidentified	Vertebrae + rib	5	1	750
I-6	Cyprinidae	<i>Squalius cephalus</i>	Vertebrae + pharyngeal bone	12	1	700
I-6	Cyprinidae	Unidentified	Vertebrae + rib + parasphenoid	16	2	550–850
J-6	Cyprinidae	Unidentified	Vertebra	1	1	600
I-6	Percidae	<i>Perca fluviatilis</i>	Scales	12		
		Unidentified fish	Fragments	121		

activity. Nevertheless, more information about dating and taphonomic analyses are required to support this assumption.

The micromammals can be assigned to *Rodentia* and are represented by a lower right M2 which has been assigned to *Microtus ex gr. arvalis-agrestis* (MNI = 1). The presence of such species may indicate a rather open environment, although it is impossible to estimate the degree of humidity due to the small number of collected anatomical elements. Some bone surfaces seem to be altered, but no digestion marks were observed and it is therefore not possible to confidently explain the origin of these elements at the site.

Isotopic results from the animal bone collagen extracted and analysed from Abri du Maras level 4.1 are presented in Table 5 ($n = 9$; %C, %N and C/N also presented) and shown in Fig. 5.

Apart from a single sample (s-eva-30226), the atomic C/N ratios of the analysed samples range between 3.1 and 3.5, and are therefore within the expected range for well-preserved bone (after van Klinken 1999), a range confirmed by recent experimental data (Dobberstein et al. 2009). The majority of samples have %C and %N resembling that of modern collagen (van Klinken 1999), and although a minority of samples have <11%N, C/N ratios all lie within the acceptable range. The collagen preservation displayed in level 4.1 is unusual for

Table 5 Stable carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotope ratios of faunal bone collagen extracted from level 4.1, including %C, %N and C/N

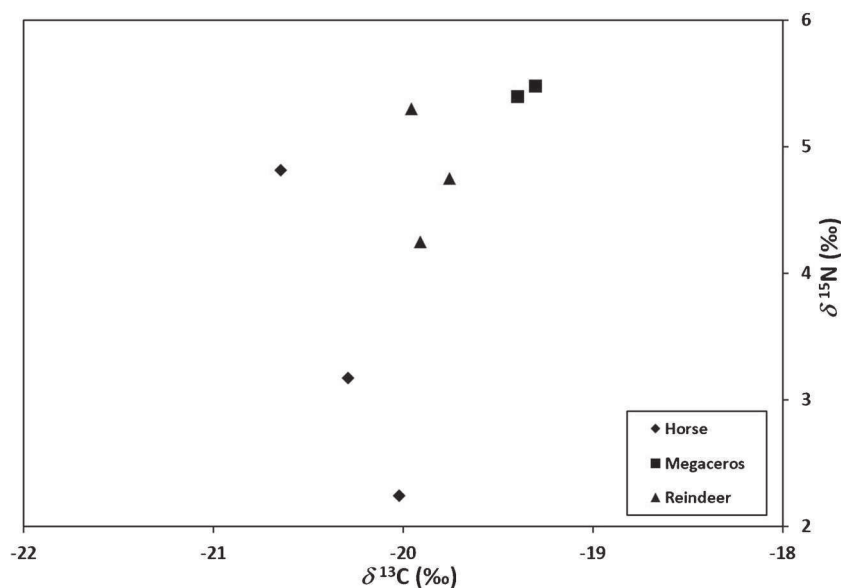
s-eva no.	Taxa	Bone	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	%C	%N	C/N
30051	<i>Equus</i>	Metacarpal III	-20.6	4.8	28.0	9.4	3.5
30050	<i>Equus</i>	Mandible	-20.3	3.2	35.0	12.0	3.4
30226	<i>Equus</i>	Mandible	-24.9	1.0	2.4	0.4	6.9
30052	<i>Equus</i>	Mandible	-20.0	2.2	31.4	11.1	3.3
30053	<i>Megaloceros</i>	Mandible	-19.3	5.5	28.3	10.2	3.2
30054	<i>Megaloceros</i>	Maxilla	-19.4	5.4	27.8	9.9	3.3
30056	<i>Rangifer</i>	Mandible	-19.8	4.7	26.9	9.5	3.3
30057	<i>Rangifer</i>	Mandible	-20.0	5.3	36.1	13.2	3.2
30055	<i>Rangifer</i>	Mandible	-19.9	4.2	32.0	11.6	3.2

material of this age, although collagen has been successfully extracted from other archaeological sites of similar or even older ages in Northern Europe (e.g. Britton et al. 2012, Jones et al. 2001, Richards et al. 2008, Kuitens et al. 2015).

As shown in Table 5 and Fig. 5, despite the small number of samples, inter-species differences in both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ are apparent, albeit with a greater range in $\delta^{15}\text{N}$ values. *Equus* values exhibit both the lowest mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values, indicative of grazing, with *Rangifer* $\delta^{13}\text{C}$ values slightly elevated, which is commonly attributed to the consumption of lichens. However, the most elevated $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values are exhibited in the two *Megaloceros* samples. This is unusual, as previous isotope studies of pre-LGM *Megaloceros* bone collagen from south-west France indicated them occupying a similar niche to red deer (*C. elaphus*) (Immel et al. 2015), with lower $\delta^{13}\text{C}$ (relative to reindeer) associated with leaf feeding in forested environments (Bocherens 2003, Drucker et al. 2008). These values are therefore likely reflecting the contemporary environmental and ecological suite of this part of France (i.e. a lack of extensive woodland cover) and also serve to confirm variability in *Megaloceros* dietary niche, which is consistent with the suggestion that this species was a mixed/opportunistic feeder (Chritz et al. 2009). Elevated $\delta^{13}\text{C}$ values were also determined in Irish *Megaloceros* dental enamel in a previous study and were related to the consumption of plants such as forb species or sedges, which typically exhibit more positive $\delta^{13}\text{C}$ values (Chritz et al. 2009, p. 142). The higher $\delta^{15}\text{N}$ values seen in *Megaloceros* at Abri du Maras could also be consistent with this. The elevated $\delta^{13}\text{C}$ could also be consistent with the consumption of mosses or lichens, as with reindeer. However, the rumen microbiology of modern (and presumably archaeological) reindeer/caribou, unlike other extant deer species, is adapted for lichen consumption (Sundset et al. 2008), and it is not known if this would have been the case for *Megaloceros*. Overall, a range of ca. 3‰ is observed in $\delta^{15}\text{N}$ values across the dataset (from 2.2 to 5.5‰), and there are clear inter-species differences, which probably reflect these different niche feeding behaviours.

Tooth microwear data for the reindeer (Table 6) were obtained from eight specimens out of the 14 moulded specimens from level 4.1. Six specimens were excluded for taphonomic

Fig. 5 Stable carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotope ratios of faunal bone collagen extracted from level 4.1 (Graph by K. Britton)



reasons (weathering or root alterations). The average number of scratches and pits, as well as the 0–17%, indicates a diet that can be classified as grass-dominated mixed feeding. Compared to other samples of fossil reindeer (Table 6), the population from the Abri du Maras is similar to that of Portel-Ouest (south-west France) (Fig. 6). The average number of pits, as well as other variables like the percentage of large pits or scratch width, are very similar, suggesting the same dietary traits at both sites. This resemblance is probably related to a similar environmental context in Southern France during the Late Pleistocene. The horse is only represented by two teeth, but even with a very small sample size, the microwear pattern indicates pure grazing (Fig. 7).

The charcoal study was based on the analysis of only 17 charcoal fragments handpicked during the excavation among a great quantity of very small-undetermined fragments. The analyses of the charcoal remains were carried out using the standard procedure following the anthracological method (Chabal et al. 1999). Each charcoal piece was fragmented by hand to observe three anatomical wood sections (longitudinal, tangential and radial). The observation was carried out with a

metallographic microscope (Olympus BX-41) with reflected light and bright and dark fields with $\times 50$, $\times 100$, $\times 200$ and $\times 500$ magnifications. The Schweingruber (1990) wood anatomy atlas was used to support the identifications. The remains from Abri du Maras are probably related to the use of fuel. Three different taxa, comprising *Betula* (birch) (13 fragments), *Pinus sylvestris* type (scots pine type) (2 fragments) and cf. Fabaceae (1 fragment) and 1 undetermined fragment. *Betula* is the most abundant; however, due to the low number of fragments, the taxa should be considered to be equally represented. These results are similar to those from the other layers from Abri du Maras, where *P. sylvestris* type is the most recurrent taxon throughout the sequence (unpublished report; Moncel et al. 2015). However, level 4.1. is the only level with *Betula*. *P. sylvestris* includes the three mountain types *P. sylvestris*, *Pinus uncinata* and *Pinus nigra* ssp. *salzmanni*, which cannot be distinguished due to their similar wood anatomy (Schweingruber 1990). These taxa correspond to heliophilous trees growing under dry and cold conditions. *Betula* can also grow under cold conditions but needs higher soil humidity rates. Both taxa are coloniser species and could

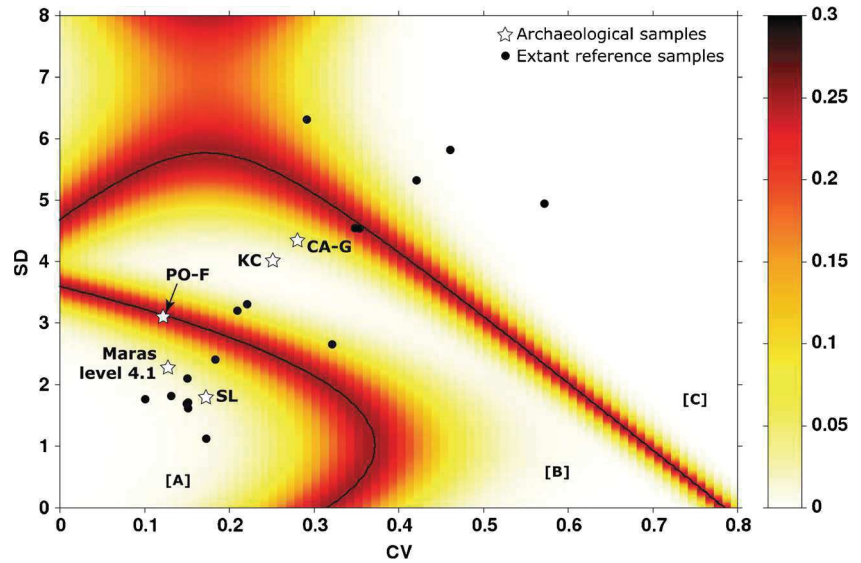
Table 6 Tooth microwear summary for the reindeer (*R. tarandus*) from level 4.1 of Abri du Maras and other Middle and Late Pleistocene localities (data from (1) Rivals et al. 2015a and (2) Rivals and Lister 2016)

Locality	N	NP	NS	SD	CV	%LP	SWS	%XS	%0–17
Abri du Maras	8	20.06	18.25	2.299	0.126	0.0	1.13	37.5	25.0
Salzgitter Lebenstedt (1)	82	29.12	10.87	1.827	0.170	47.6	0.94	4.9	97.6
Kent's Cavern (2)	12	15.50	15.63	4.012	0.257	25.0	1.33	50.0	75.0
Portel-Ouest F (1)	30	23.23	25.35	3.097	0.122	3.3	1.13	60.0	0.0
Caune de l'Arago G (1)	11	14.15	17.41	4.380	0.281	12.0	0.88	35.0	52.9

Percentage of individuals with less than 17 scratches, i.e. within the browsing range = 0–17%

N number of specimens, NP average number of pits, NS average number of scratches, SD standard deviation on NS, CV coefficient of variation on NS, %LP percentage of individuals with large pits, SWS scratch width score, %XS percentage of individuals with cross-scratches

Fig. 6 Microwear data (Graph by F. Rivals). Boundary lines with the error probability (heat map) based on SD and CV values of microwear data used for the classification of samples into short events (region A), long-term events (region B) or two separated short events (region C). Black dots indicate modern reindeer populations used to build the model. White stars indicate archaeological samples: Abri du Maras (level 4.1), Salzgitter Lebenstedt (SL), Portel-Ouest level F (PO-F), Kent's Cavern (KC) and Caune de l'Arago level G (CA-G)



form part of open forests or forest grooves. *Betula* has also been described in other sites from, for example, Northern Iberia where it is related to increased precipitation and a more humid environment (Uzquiano 2008). The results from the charcoal analyses back up the characterisation of mosaic environments during MIS 3 with open landscapes but also arboreal cover. Other European anthracological records show similar patterns with a dominance of conifer forests and *Betula* as the main arboreal cover. These species would probably coexist, as also observed in other MIS 3 records from Northern Iberia and Central France (Théry-Parisot and Meignen 2000; Théry-Parisot and Texier 2006; Uzquiano 2008; Uzquiano et al. 2008; Uzquiano et al. 2012).

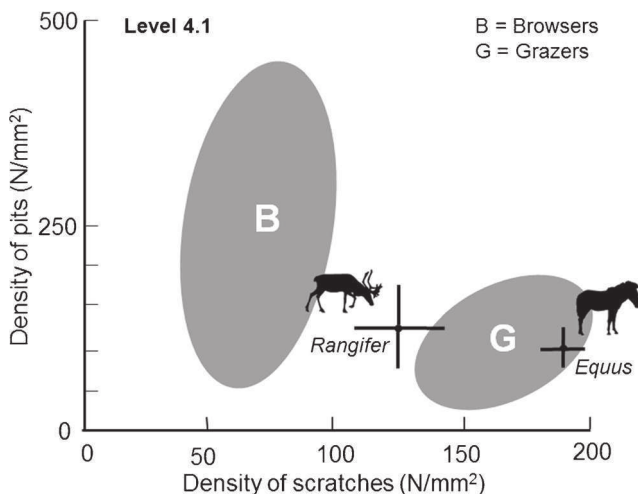


Fig. 7 Bivariate plot of the average densities of pits and scratches in reindeer and horse (Graph by F. Rivals). Bars correspond to the standard deviation (± 2 SD) for the fossil samples. Grey areas correspond to the Gaussian confidence ellipses ($p = 0.95$) on the centroid for extant leaf browsers (B) and grazers (G) from Solounias and Semperebon (2002)

Neanderthal hunting: animal population and seasonality

The 16 reindeer individuals are composed of seven juveniles, two young adults, two prime age adults, three old adults and two senile individuals (Table 3). No foetal remains were discovered, probably because of the differential bone preservation of the sample. This age distribution shows a majority of young individuals. Once plotted on a ternary diagram and after correction as mentioned above in the Section 3, the reindeer population falls into an L-shaped zone (living structure or catastrophic mortality profiles) (Fig. 8). As noted above, unfortunately, the bad preservation of the reindeer bones and antlers precludes any morphometric and thus sex ratio analyses.

Taking into account the period of birth for reindeer (May–June) and the period of death for young individuals, four

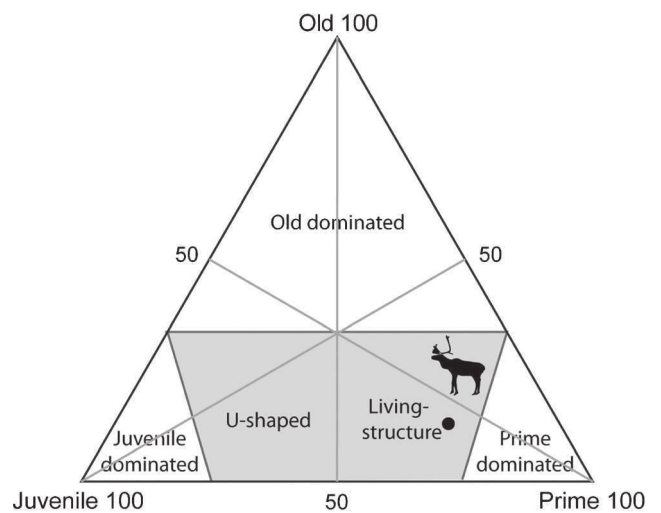


Fig. 8 Ternary diagram for reindeer age classes (modified from Stiner 1990) (Graph by C. Daujeard)

juveniles died during the fair season (possibly from spring to summer) and five others during the autumn (from September to December). Two juveniles are about 3–5 months old, two are 12–15, one is 17–20 and two are 22–27 months old. Two sub-adults (category young adult) died at the age of 27 to 30 months.

Regarding cementochronology, out of the nine studied samples in level 4.1, only four gave positive results (Table S3). They correspond to four reindeer teeth and indicate periods of death during the autumn. These results confirm those based on the periods of tooth eruption, i.e. a majority of animals died during the late summer and autumn. This period corresponds to the present-day great migrations (end of summer and then end of autumn) and rut (October) periods for reindeer (after Miller, 1971), a time of the year when all age classes and both sexes herd together.

Age determination was possible in a small number of individuals of other taxa (Table 3), although ages were mixed and there were insufficient numbers for any clear trends to emerge. The horse series yielded one deciduous foal incisor (0–3 months old) indicates a period of death during the summer (births in early May).

The variability of scratch microwear density is used as a proxy for the duration of occupation at archaeological sites. In the case of level 4.1 of Abri du Maras, it corresponds to low variability both in terms of CV and SD (Table 6). Such values fall within the area of seasonal events (or shorter), i.e. area [A] on Fig. 6. Values are similar to the signal observed for the reindeer from Salzgitter-Lebenstedt (Germany), where animals (MNI = 86) were hunted during a seasonal event in the fall (Gaudzinski and Roebroeks 2000; Rivals et al. 2015a). The pattern is significantly different to that reported for longer-term occupations (longer than a season), as at Kent's Cavern (UK) or level G of the Caune de l'Arago (France).

Carcass transport and processing

For reindeer, for %MAU and survival rates for each anatomical element, upper and lower long bones largely dominate the distribution (Fig. 9 and Table S4). Among them, we observe a strong and positive correlation between the volume of the marrow cavity and %MAU of long bone elements (with Spearman's $r_s = 0.82$, $df = 9$ and $t = 7.66$: $p < 0.001$). The good representation of tibias and metatarsals, which have among the highest marrow contents, must be moderated, as it is easier to determine them. Taking into account the seven main carcass portions (%MAU), the skeletal profile underlines the scarcity of the head and of the limb extremities, the near absence of the vertebral column and the predominance of forequarters and hindquarters (Fig. S5). No correlation exists between FUI indexes and %MAU for all types of reindeer elements (with Spearman's $r_s = -0.04$, $df = 13$ and $t = -0.19$: $p > 0.8$). However, before interpreting these data in terms of

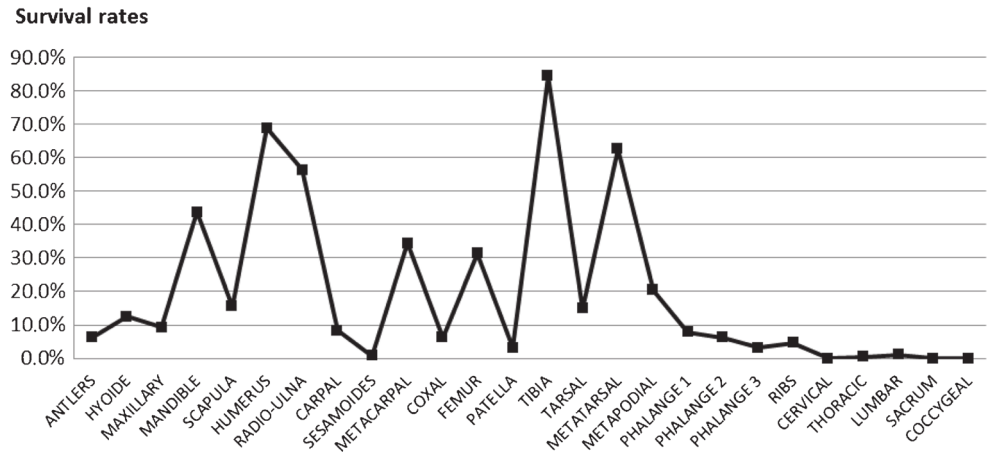
human strategies, we have to consider the positive correlation between MAU rates and density indices (see above). This indicates some preservation bias of the bone assemblage. Nevertheless, the deficiency of isolated teeth and cervid antlers confirms the rarity of heads (Figs. 9 and S5). Similarly, the scarcity of basipodials and phalanges cannot be explained by a problem of determination or density and thus highlights a real absence (selective transport or in situ carcass processing, i.e. crushing). Regarding the quantity of oleic acid within the appendicular elements, which appears to be the richest in the extremities, we must underline here the apparent scarcity of the phalanges. Finally, it is difficult to specifically determine ribs and vertebrae, but all parts of these elements, even the densest ones, are rare (%MAU = 0–5%; Table S4), in the same way as the indeterminate elements belonging to the middle-sized ungulate category. Thus, here too, we can consider the rarity of the trunk as a reality.

For the other animals, the number of remains is not sufficient to calculate the MAU, but based on the NISP, we can make some comments (Table S4). For the horse, we observe the same rarity of the trunk (with only one rib fragment) and inversely the important presence of heads. Bison is represented by two isolated teeth and six hindquarter elements. The giant deer comprises 20 elements, made up of head, trunk and long bone elements. Red deer is only represented by six long bone remains, from forequarters and hindquarters. Caprines count four isolated teeth and only one femur shaft fragment. As for lagomorphs, rabbit remains comprise one isolated tooth and one metacarpal and the hare one scapula, one humerus and one tibia. Indeterminate lagomorphs regroup two isolated teeth, one scapula, one humerus, one radius, one phalange, one femur, one tibia and two indeterminate elements.

Of the decipherable remains, 21.8% bear cut marks, scraping marks and incisions made by sharp lithic tools. All the main ungulate species have been processed (Table 7). Slightly less than a third of the reindeer and horse elements bear cut marks. Some bison, red deer and giant deer portions also show butchery striations. Concerning the *chaîne opératoire* of carcass processing, depending on the taxa, various stages were processed in the shelter: skinning, dismembering and retrieving tendons, periosteum, flesh, marrow and possibly bone grease removal.

Reindeer include 199 bone elements with cut marks. Most of these are long bone shafts (Table 8; Fig. 10). The forelimbs were skinned, as indicated by numerous metacarpal fragments with oblique and parallel incisions of various lengths spread along the anterior and medial faces, and then dismembered (humerus/radius-ulna) and defleshed. This latter step is mostly represented on humerus and radius-ulna by oblique or longitudinal striations spread along the shafts. Tendons were retrieved resulting in transverse marks on the posterior face of some

Fig. 9 Distribution of the skeletal elements for reindeer by anatomical parts (Graph by C. Daujeard). Survival rates calculation corresponds to $MAU \times 100 / NMI_{max}$



metacarpals. Six fragments of metacarpals bear scraping marks as well as longitudinal long incisions representative of periosteum removal before marrow extraction. One vestigial metapodial displays 30 short and oblique cut marks typical of the skinning process. As for the hind limbs, metatarsals point to skin, periosteum and tendon removal, femurs and tibias were defleshed and disarticulation was observed, for tibia/femur on three proximal tibias and for tibia-tarsal on two distal tibia portions and one astragalus with short and deep cut marks on its medial surface. Two fragments of cut-marked mandibles indicate the recovery of cheek meat. Finally, seven rib fragments are cut marked, some due to evisceration, but most of them as a result of defleshing.

For the horse, cut marks show forelimb dismembering (humerus/radius-ulna) and flesh (cheek) removal on two mandible fragments, two tibias and one femur. Bison remains comprise two tibia shaft fragments with filleting marks and one metatarsal fragment with scraping and skinning marks. Evidence of giant deer skinning is present on a metatarsal bone, defleshing on a tibia shaft and evisceration on a lumbar vertebra. One red deer humerus bears a dozen short and deep

cut marks on its lateral epicondyle (distal end), indicating disarticulation.

Five of the 10 lagomorph elements highlight the presence of cut marks and/or green bone fracturing. These elements are the distal extremity of a hare humerus, two proximal scapula portions (hare and indeterminate), two femur shaft fragments and a tibia (indeterminate), showing meat removal and the disarticulation process.

Marks with diagnostic criteria of intentional anthropogenic breakage are present on 481 remains of taxonomically identified ungulate long bones. These marks are mainly percussion notches or impact flakes. Incipient percussion pits are rare (1) and peelings were not observed, partly due to the poor conservation of the bone surfaces (root etching). We did not identify any adhering flakes. Concerning positive flake scars, only eight *boutons de manchette* were observed, mostly in shaft bone fragments (undetermined bones). Long bone shaft parts present the highest rates of percussion marks (99%), distributed over the diaphysis surface with no preferential location

Table 7 Number (NRcut) and rates (%NRcut) of cut-marked remains by taxa

Taxa	NRcut	NRl	%NRcut
<i>Equus ferus</i> cf. <i>germanicus</i>	8	26	30.8%
<i>Bison priscus</i>	3	4	–
<i>Cervus elaphus</i>	1	2	–
<i>Megaloceros giganteus</i>	3	14	21.4%
<i>Rangifer tarandus</i>	199	719	27.7%
Lagomorphs	5	10	50.0%
IND recorded	230	1288	17.9%
Total	449	2063	21.8%

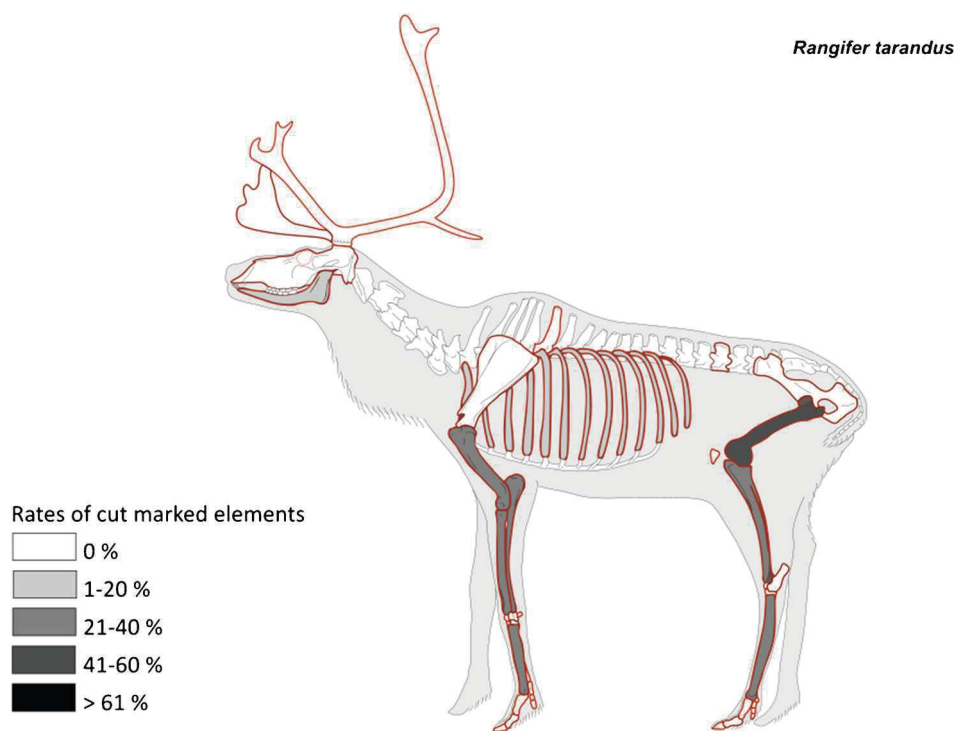
NRl number of legible remains

Table 8 Number (NRcut) and rates (%NRcut) of cut-marked elements for reindeer

	NRcut	NISPl	%NRcut
Mandible	2	17	11.8
Ribs	7	36	19.4
Humerus	15	45	33.3
Radius-Ulna	25	115	21.7
Metacarpal	20	53	37.7
Femur	13	26	50.0
Tibia	55	152	36.2
Astragalus	1	2	–
Metatarsal	45	155	29.0
Metapodials	12	54	22.2
Vestigial metapodials & phalanges	2	4	–
Indeterminate shafts	2	–	–

NISPl number of legible identified specimen

Fig. 10 Disposition and rates of the reindeer remains bearing cutmarks (circled in red: the bone elements present in the level 4.1; cf. Table 7)



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D'après : Fontana (Laure). — Mobilité et subsistance au Magdalénien dans le Bassin de l'Aude. *Bulletin de la Société préhistorique française*, tome 96, n°2, 1999, fig. 9, p. 182.

(Vettese 2014, Vettese et al. 2017). Only six articular portions display percussion marks. Regarding taxa distribution, the giant deer (33%) bears the highest proportion of percussion notches, followed by the horse (29%), red deer and reindeer (25%) and bison (17%). Notches are more abundant on tibiae and humeri (37%), femurs (35%) and then metacarpals (22%), metatarsals (20%) and radio-ulnas (18%). Apart from long bone elements, a few horse and reindeer mandibles and three calcanei were fractured for recovering marrow. All the phalanges were complete or almost complete.

Burning damage was observed on 20.7% of the faunal remains (Table 9). The majority of these remains are

represented by small fragments with a length of less than 25 mm (95.4%). In that size category, compact bones are dominant. Nevertheless, spongy carbonised bone fragments of all sizes represent a quarter of the burnt elements. The rate of carbonised bone fragments reaches 81.4%. Based on experimental and archaeological data (Costamagno et al. 2009), those data are commonly interpreted to reflect the use of bone for fuel, which confirms the other evidence of burning at the site provided during the fieldworks (see above Section 2.3). The low percentage of burnt spongy bones may be due to their high vulnerability to atmospheric agents (Gerbe 2010).

Table 9 Characteristics of burnt elements

	c1	c2	c3	c4	c5	c6	c7	total	Percent	NR	Percent
Spongiosa 0–25 mm		75	309	80	42	14	1	521	22.6%	1890	27.6%
Compacta 0–25 mm	11	318	1008	214	83	30	14	1678	72.8%	6503	25.8%
Spongiosa 26–50		1	4	6	4			15	0.7%	320	4.7%
Compacta 26–50	4	8	12	11	1	1		37	1.6%	1129	3.3%
Comp-spong > 50	1	4	1					6	0.3%	1050	0.6%
Isolated teeth		6	21	8	9	3	2	49	2.1%	231	21.2%
Total	16	412	1355	319	139	48	17	2306	100.0%	11,123	20.7%
At least carbonised (c3 to c7)								1878	81.5%		
At least calcined (c4 to c7)								523	22.7%		
Burnt elements < 25 mm								2199	95.4%		
Spongious elements (c3 to c7)								460	24.5%		

Out of the 19 identified burnt bone elements, it is noteworthy that most of them are spongy elements: four are short articular bones (one lunate bone, one hamate bone and two malleoli), one is a vertebral element (axis fragment), one is a mandible fragment and 13 are long bone portions (shaft and articular portions).

Lastly, only one small shaft fragment presents retouching marks on its surface. This artefact was burnt (carbonised) and remains indeterminate. The marks are situated on the apical zone and can be associated with sliding striations due to contact with lithic cutting edges. They are short (< 10 mm), dispersed and perpendicular to the long axis (Patou-Mathis and Schwab 2002).

Discussion

Assessing the origin of a faunal accumulation necessitates the consideration of numerous aspects, such as the archaeological and sedimentological context, as well as taphonomic data. At Abri du Maras, all the data point towards an almost exclusively human accumulation. Spatial analyses underline the close association between the faunal and lithic remains unearthed in level 4.1, indicating one distinct occupation phase. Furthermore, the numerous faunal refits ($n = 65\text{--}148$ elements) and anatomical connections ($n = 22\text{--}68$ elements) identified in this level, associated with the short distances between connecting elements, attest to its homogeneity and sub-contemporaneity. In addition, the numerous butchery marks ($\approx 20\text{--}30\%$ of the NISP), burnt bones and green bone breakage (70% of long bones), as well as the absence of carnivore remains and the scarcity of carnivore impacts on bones (< 1%), allow us to identify this faunal accumulation as human. In this exceptional almost exclusively human accumulation context, data from age and skeletal profiles, as well as seasonality, can be used to assess Neanderthal subsistence behaviours, in a well-defined palaeoenvironmental context.

Palaeolandscapes of MIS 3: a new framework

The combination of data, such as the faunal spectrum combined with extant herbivore ecological data, isotopes and tooth microwear, enables us to define the palaeoenvironments in level 4.1 at Abri du Maras. The predominance of reindeer in the faunal spectrum, associated with horse and bison suggest open and steppe landscape, while the presence of ibex highlights the rocky landscapes. Additionally, the identification of *Microtus arvalis-agrestis* within the microfauna supports the idea of an open environment. The presence of (what are typically considered) browsers, such as giant deer and red deer, however, could be indicative of the presence of woodland (see Ecker et al. 2013 for references). Nevertheless, the well-known plasticity of the red deer (Straus 1981; Guérin and

Patou-Mathis 1996; Discamps and Royer 2017) associated with the unusual isotope values obtained in this study for the giant deer contributes to highlight that those species were exploiting different ecological niches. Indeed, whereas the isotope data from horses is typical of grazers, the relatively high $\delta^{13}\text{C}$ observed in giant deer specifically do not suggest feeding in woodland areas but instead could indicate mixed feeding in open environments, indicating that this species was also, like the red deer, an opportunistic feeder. The $\delta^{15}\text{N}$ values show clear inter-species differences, consistent with various niche feeding behaviours on plants with varying $\delta^{15}\text{N}$ values. Tooth mesowear and microwear indicate an intermediate position between grass and browse feeders for reindeer and for horse a graze-dominated diet. Data for reindeer and horse are consistent here with those of the carbon stable isotope values, i.e. no clear habitat preference for reindeer (mixed feeder, incorporating lichens or other browse) and contrariwise preference for open landscape grazing for horse. The analysis of red deer bone collagen and tooth wear for giant deer from the site in a future might illuminate the extent of this woodland.

Although broadly a cool, open environment, the pedosedimentary facies at the site does suggest occupation during short humid episodes with pronounced pedological development that alternate with drier and cooler phases dominantly marked by accumulation of aeolian dust during the uninhabited periods. This may be indicative of the abandoning of the landscape by Neanderthals during the harshest periods. Finally, charcoal data identify the predominance of birch relatively to scots pine in the level 4.1, indicating sufficient humidity for the development of birch forests. Thus, these data confirm a cool yet moister climate than expected by the faunal spectrum and thus reinforce the characterisation of the mosaic environments during the MIS 3 with open lands but also some arboreal cover. Finally, despite the dating margins of error, human occupations of the level 4.1 of Abri du Maras, dated between 40 ± 3 and 46 ± 3 ka ($n = 2$) (Richard et al. 2015), may correspond to the warm event or Dansgaard-Oeschger event 12 (DO#12) observed in the Villars speleothem records, just preceding the H4 cooling event, contemporaneous of the Neanderthal demise in western Europe (Genty et al. 2010). According to this study, DO#12 was likely warm and humid with fast growth rate and low $\delta^{13}\text{C}$, consequence of intense soil and vegetation activity.

Selective mass reindeer predation at level 4.1 of Abri du Maras?

With 88% of the NISP, reindeer is the most represented taxon in the faunal spectrum. The richness and diversity indexes highlight a spectrum similar to monospecific ones, such as Les Pradelles (Evenness = 0.23 in level 9 and 0.36 in level 10; Costamagno et al. 2006), Le Lazaret-UA25 (Richness =

1.41 and Shannon = 1.5 for MNI) and the Proto-Magdalenian level of Abri Pataud ($H < 1$) (see Valensi et al. 2013) for cervids (among others). Large bovid-dominated faunal assemblages are also numerous, with examples such as Mauran (Farizy et al. 1994; $E = 0.05$ and $1/D = 1.02$, in Grayson and Delpech 2002 and $E = 0.04$ in Rendu et al. 2012), La Borde (Jaubert et al. 1990; $E = 0.16$ and $1/D = 1.098$, in Grayson and Delpech 2002) in France or Wallertheim in Germany (Gaudzinski 1995). Even dangerous and solitary species such as the rhinoceros were selectively hunted by humans with the famous example of Taubach in Germany (Bratlund 2000). According to the study of Gaudzinski-Windheuser (2006), such anthropogenic monospecific faunal spectra increased significantly all over Europe from MIS 5 onwards (see also above in Section 1).

The age distribution of the 16 reindeer individuals from level 4.1 indicates a living structure. Age profiles pointing to catastrophic mortality are representative of natural disasters, mass kills or non-selective hunting episodes (Lyman 1987; Stiner 1990; Discamps and Costamagno 2015). Mass kills or non-selective slaughters within the herds are both plausible. Similar age profiles have been observed for other Middle Palaeolithic cervid accumulations, such as Salzgitter-Lebenstedt (MNI = 86), Les Pradelles (level 9, MNI = 33; level 10, MNI = 22), Roc de Marsal (Layer 4, MNI = 12/estimated MNI = 78), Jonzac (Layer 22, MNI = 18) or Pech de l'Azé IV (layer 4, MNI = 25) for reindeer (Gaudzinski and Roebroeks 2000; Costamagno et al. 2006; Niven et al. 2012; Niven 2013; Castel et al. 2017), as well as Pech de l'Azé I (level 4, MNI = 19) for red deer (Rendu 2010), considered to be the result of non-selective hunting. Inversely, some bovid-dominated assemblages, such as Wallertheim (level B1, MNI = 52) (Gaudzinski 1995), show repeated, selective and controlled collective hunting episodes, indicating that human strategies are not the same, depending on the hunted species and environments. All these sites display one single dominated species, and the only difference lies in the number of individuals, mainly depending on the excavated surfaces and the number of human occupation episodes.

At Abri du Maras, seasonality indices can be linked to human hunting activities. Indeed, added to the presence of unretouched Levallois points used as projectile tips and large Levallois blades and points brought to the site (Hardy et al. 2013; Moncel et al. 2014), the taphonomic analysis (see above) clearly associates the faunal assemblage with planned hunting activities. The seasonal indices for level 4.1 show that most of the reindeer deaths occurred during the autumn (September to December). Furthermore, tooth microwear data correspond to seasonal events, similar to those observed for reindeer from Salzgitter, which reflect short-term mass death scenarios during the same period around September. The three short-term stopping places of Les Pradelles, Jonzac and Salzgitter show the same period of death for reindeer

(Gaudzinski and Roebroeks 2000; Costamagno et al. 2006; Niven et al. 2012), coinciding with the reindeer's fall migrations. Fall migration is a time of the year where herds are not segregated and males (before and during the rut) and females are in particularly good physical condition, optimising energy return for hunters. Even among sedentary ecotypes, fall is the period where body condition is optimal and fat reserves are highest in *Rangifer*, following summer feeding. Unusually, at Pech de l'Azé IV, humans seem to have hunted reindeer during their spring migration.

Concerning the skeletal profiles, long bones largely dominate the accumulation, and among them, the richest elements in marrow, indicating primary carcass processing on the kill site and then selective transport of the carcass elements. The scarcity of the axial skeleton (head and trunk) and of the limb extremities (short articular bones) could indicate their abandonment at the kill site and/or an in situ differential and/or spatial preservation or treatment. These data may be related to the significant and positive correlation between bone density and the %MAU, highlighting the rarity of the less dense bone portions on the site (mainly long bone extremities and axial skeleton). Nevertheless, as indicated above, the rarity of isolated teeth and antlers confirms the absence of the heads. Concerning the trunk, all portions are scarce, even the densest ones and also indeterminate elements. Thus, the near absence of the axial skeleton cannot be entirely explained by the post-depositional destruction of low-density elements and we can instead postulate that these parts were frequently abandoned at the kill site and/or exploited and thus destroyed by Neanderthals once transported to the site. As for the paucity of carpals and tarsals, the presence of metapodials and of other limb portions at the site raises questions as to their in situ disappearance. As these parts are not particularly fragile, this may also result from specific in situ treatment rather than differential preservation. The scarcity of phalanges is more easily explained, suggesting the hypothesis of skin exportation. However, specific spongy bone processing at the site, i.e. for grease bone extraction, including articular portions as well as vertebral elements, may also be a valid explanation, although difficult to identify archaeologically (Daujeard 2008; Costamagno 2013; Speth 2015). Indeed, bone grease processing implies a great fracturation of the bone and a quasi-exclusive use of spongy elements (Costamagno and Rigaud 2014). Because of their intense fragmentation, those pieces may be more subject to post-depositional diagenetic processes, largely highlighted here, and thus to differential destruction. However, according to Morin and Soulier (2017), excepted in case of crushing the spongy portions to obtain a raw bone meal, the grease extraction by boiling may have left some coarse identified fragments among the assemblage. Thus, without excluding this possibility, we may emphasise another hypothesis to explain the quasi-absence of spongy bones at Abri du Maras (4.1), i.e. the use of bone for fuel (see the results above and Table S7).

At Roc de Marsal, interestingly, the authors (Castel et al. 2017) observe the same scarcity of heads (including antlers), short articular elements, phalanges and the axial skeleton, as a result of the combination of different causes: in situ differential preservation, in situ specific treatment and the abandonment of some carcass elements at the kill site. Concerning spongy bone treatment, the main difference between both sites lies in the lack of fire evidence at Roc de Marsal and conversely in the many fire indices at Abri du Maras: ash lenses and numerous burnt bones. Nevertheless, other types of carcass exploitation behaviours exist in the Middle Palaeolithic reindeer-dominated assemblages. For example, at Jonzac, the skeletal profiles indicate the transport of whole carcasses to the site, whereas at Les Pradelles (levels 9 and 10), which is considered as a secondary butchery site, Neanderthals may have mostly selected upper long bones and then exported some fleshy portions to another camp. Due to the absence of evidence of fire and the presence of carnivore tooth marks on bones at Les Pradelles, the same hypotheses regarding the scarcity of spongy bone elements at this site cannot be advanced. At Pech de l'Azé IV, the most nutritious body parts were selectively transported to the site. At the open-air site of Salzgitter-Lebenstedt, the data point towards the hunting of high-quality animals and the in situ processing of limb bone elements for flesh and marrow, with possible evidence of food storage, as at Les Pradelles (Gaudzinski and Roebroeks 2000; Costamagno et al. 2006). In general, in all these reindeer-dominated assemblages, except those of Salzgitter and Jonzac, which served as primary butchering locations where reindeer skeletons were mostly retrieved complete, we observe a deficiency of the axial skeleton (heads, vertebrae and ribs), as well as the girdles (pelvis and scapula) and the short articular bones (carpals, tarsals and phalanges). All these parts cannot be equally affected by low-density differential preservation, and thus large carcass portions appear to have been abandoned at the kill site during the early butchery stages (disarticulation) and/or affected by specific anthropogenic treatment at the base camp (grease bone extraction and/or use of bones as fuel). The lack or scarcity of fire evidence in many of these places, such as Roc de Marsal, Pech de l'Azé IV (layer 4), Les Pradelles, Jonzac or Salzgitter, may point towards a combination of the frequent abandonment of the trunk, short articular bones, heads with antlers as well as skins, including phalanges and in situ grease extraction of the transported spongy elements. This moderate presence of skulls and minor presence of phalanges, associated with a representation of the limb bones relative to marrow contents, has already been highlighted for reindeer assemblages from the Middle Palaeolithic (Gaudzinski-Windheuser and Niven 2009).

Finally, at Abri du Maras, the numerous cut-marked elements, associated with the almost systematic green bone breakage of limb elements for marrow recovery and the

possible use of bones for fuel, indicate intensive in situ carcass treatment and consumption. All stages of the butchery process are identified: from evisceration, to skinning, disarticulation, defleshing and the removal of tendons. Nevertheless, due to the lack or the scarcity of certain skeletal parts (vertebrae, ribs and long bone extremities), evisceration and disarticulation are very poorly represented. As for long bone breakage for marrow, 85% of the long bone remains bear green bone fractures. This rate is high but still moderate compared to other anthropogenic faunal assemblages where the near totality of yellow marrow bones are fractured, including not only long bones but also phalanges, tarsals and mandibles (i.e. Les Pradelles or Roc de Marsal in south-western France: Costamagno et al. 2006; Castel et al. 2017 or Saint-Marcel or Sainte-Anne I in the Southeast: Daujeard 2007; Daujeard et al. 2012). Here, very few mandibles and calcanei and no phalanges present green bone breakage. Some anatomical connections (limb bone elements) and whole long bones, especially reindeer metacarpals, were found in level 4.1. The same behaviour has also been observed at Jonzac and Salzgitter-Lebenstedt, where, at the latter site, Neanderthals frequently discarded poor long bone elements and some metacarpals were abandoned whole. In all these reindeer-dominated assemblages, evidence of in situ meat filleting and marrow exploitation by Neanderthals has been documented, associated with very scarce indices of carnivore action. The rarity of the presence of traces of fire, only recorded in the level 4.1 of Abri du Maras, may indicate different site functions and possibly longer occupation durations.

At Abri du Maras (level 4.1), the clear monospecific spectrum, catastrophic mortality and autumnal deaths point to short-term hunting episodes of migratory mixed herds. At that time of the year, Neanderthal groups focused on preferential prey, predominantly available in the surroundings. However, as underlined by Costamagno et al. (2006), the question of 'obligate' versus 'deliberate' specialisation is very difficult to assess (see below). Likewise, it is very difficult to discern between successive individual hunting episodes and mass kills. Many criteria, such as sedimentation rates, refits and the volume of the excavation, must be taken into account for evaluating the presence of a single depositional episode. Unfortunately, these data are difficult to obtain in the literature and thus difficult to compare. What can be said of Abri du Maras (level 4.1) is that the presence of numerous short distances refits and of ash lenses at a same depth seems to suggest a main phase of human occupation. Like most of the reindeer-dominated assemblages (except for Salzgitter), level 4.1 has a high MNI of reindeer (between 10 and 30) and indicates that hunters regularly discarded carcass portions at the kill site. Added to the predominance of reindeer in the assemblage and catastrophic and seasonal mortality (Costamagno et al. 2006; Rendu et al. 2012; Lubinski 2013), mass procurement is the most likely explanation.

Finally, at Abri du Maras, carcasses were clearly being butchered elsewhere at the kill site and then the limb elements were commonly selected to be transported to the site. The presence of some long bones still complete or even in anatomical connections, as at the site of Salzgitter-Lebenstedt, further supports the hypothesis that level 4.1 is predominantly the product of mass hunting episodes.

Neanderthal hunting of reindeer in the Upper Pleistocene of Western Europe: selective and planned behaviour or environmental constraints?

Reindeer-dominated assemblages are a specific type of single species-dominated assemblage, associated with a seasonal hunting model. This is the case at Les Pradelles, Jonzac, Roc de Marsal, Pech de l'Azé IV in south-western France or Salzgitter in the north of Europe. Some authors argue that such assemblages result from the opportunistic response of Neanderthals to taxa availability (Niven et al. 2012; Niven 2013). Neanderthals may have hunted reindeer because of their dominance during cold periods and because of the lack of other ungulates in the environment, such as bison or horse. This observation is similar to that of Grayson and Delpech (2003) for the Magdalenian assemblages at Grotte XVI, where the increase in reindeer remains is interpreted as a direct reflection of what was available in the environment during periods of cold summer temperatures. Similarly, on a regional scale, the study of Magniez and Boulbes (2014) at Tournal Cave underlines the important role of environmental changes on the dietary behaviour of human groups during the Upper Pleistocene, from MIS 3 to MIS 2. This point of view is also supported by the data from Discamps (2013), showing important biomass fluctuations between the Quina and post-Quina periods in south-western France. According to that author, the Quina period corresponds to a low ungulate biomass episode marked by growing reindeer populations. Inversely, during the late Middle Palaeolithic, or 'Post-Quina' period, ungulate biomass increases with the highest rates of horse and bison. Nevertheless, more recent palaeoenvironmental reconstruction from large and small mammal communities (Discamps and Royer 2017) tempers those chronological changes in the South-West, underlining the importance of seasonal and geographical differences. Indeed, the latter is illustrated in the south-west for the Quercy region, where a high ungulate biomass environment persists during the Quina episode (Discamps 2013). About seasonality influence, it should be noted that while limited strontium isotope evidence suggests migratory behaviour in late Pleistocene European reindeer, this has yet to be demonstrated for bison (Britton et al. 2011, Julien et al. 2012). One other notable factor is that the faunal spectra of the reindeer monospecific assemblages of Jonzac and Pech de l'Azé IV, as well as in all Upper Pleistocene assemblages of this type, whether they are in Western or

Northern Europe, always comprise horse, bison and red deer alongside reindeer. Finally, the recent luminescence ages of Guérin et al. (2017) at Roc de Marsal (average of 49 ka, $n = 5$) suggest a longer duration for the Quina Mousterian with reindeer-dominated assemblage in south-western France, extending until MIS 3, very close to the ages obtained for level 4.1 of Abri du Maras. These new luminescence ages (Guérin et al. 2012, 2017) also confirm the association of some Levallois assemblages with mixed fauna (red deer, roe deer and reindeer) at the beginning of MIS 4 (ca. 65–70 ka) and that of others with reindeer-dominated spectra at certain moments of MIS 3 in south-western France. All those data invalidate the strict association of MIS 4 with Quina technological complex and reindeer-dominated spectra in that region, providing a more complex view of palaeoenvironmental evolution during MIS 4 and MIS 3. Thus, taking into account those difficulties in chronological resolution and environmental reconstruction, we may keep in mind the possibility that this monospecific reindeer hunting behaviour may rather reflect a preferential selection of prey, than environmental constraints (see Castel et al. 2017).

In south-eastern France, a different situation emerges with a very low number of reindeer-dominated assemblages for the Upper Pleistocene. Other Middle Palaeolithic and even Early Middle Palaeolithic single species-dominated assemblages with seasonal slaughters have been observed in the south-east. This is the case at Sainte-Anne I, Saint-Marcel, Abri Moula (interglacial levels) and Le Lazaret (UA25), with spectra largely dominated by cervids or at Baume des Peyrards, in the Vaucluse, where the ibex is the main hunted animal (Daujeard and Moncel 2010; Moncel and Daujeard 2012; Daujeard et al. 2012). Nonetheless, only some Late Middle Palaeolithic occupation phases, Baume Néron, Abri Moula and Abri du Maras, all situated along the Rhône Valley, show faunal spectra dominated by reindeer and followed by bison and horse. All these assemblages correspond to the end of MIS 4 or the beginning of MIS 3 (Defleur et al. 1994; Defleur et al. 2001; Richard et al. 2015), with cold and humid environments. At Abri du Maras, we observe different faunal spectra within a same sedimentary unit and chronological time span (Richard et al. 2015). Indeed, level 4.2, which is situated just below level 4.1, provides a more varied faunal spectrum dominated by bison and horse and followed by red deer, reindeer and giant deer. Besides that, preliminary seasonal data for the horse and giant deer from level 4.2 give different periods of human occupations, during the spring and the summer (Daujeard, in Moncel et al. 2014, unpublished report). Thus, the differences existing between these two sub-contemporaneous levels may be explained here by the planned seasonal organisation of Neanderthal groups, depending on the presence of some species in the surroundings, at local and short chronological scales, rather than on a real absence of other animal community. Indeed, the reindeer-

dominated assemblage in level 4.1 could result from selective hunting by highly mobile human populations, who knew the location of shallow river crossings (natural fords), facilitating the passage of animals across the Ardèche River, and also possibly the timing reindeer migrations along the Rhône Valley. If reindeer were indeed migratory at this time period, and in this region, the hunting of non-migratory ‘local’ animals, in smaller numbers (relative to reindeer) could also be an important buffer against the time-stress activity of interception hunting. Were the reindeer herds targeted non-migratory, and instead exhibited more local ranging behaviour, other factors could explain this selection. For example, the aggregations of males and females that occur during the rut in both migratory and sedentary herds, and the prime condition of the animals during autumn (in terms of body weight and fat percentage). The strontium isotope analysis of reindeer teeth from level 4.1 of Abri du Maras would serve to illuminate this further and help determine if reindeer targeted were indeed migratory. However, whether it was to intercept migratory herds, or to take advantage of the autumn aggregations of prime conditioned reindeer herds (migratory or non-migratory), the intense and seasonally restricted nature of reindeer exploitation at Abri du Maras infers the selective, seasonal appeal of this area for contemporary groups on their seasonal rounds. At Abri du Maras, this behaviour, highlighting planned and communal mass hunting strategies, seems here to ‘imply a deliberate selection of particular species from the total resources potentially available for exploitation’ (Mellars 1996, p. 196). Significantly, Abri du Maras confirms the deeper antiquity of the practice in another region of Europe than previously identified (mainly south-western France and Northern Germany).

Thus, the faunal analysis of level 4.1 of Abri du Maras provides evidence of a new occurrence of planned, collective and selective Middle Palaeolithic reindeer hunting, considerably further east than other well-known sites in south-western France, such as Les Pradelles, Jonzac, Roc de Marsal or Pech de l’Azé IV. Indeed, south-eastern France displays rare cases of reindeer-dominated assemblages along the Rhône valley. The sites of Abri du Maras, Abri Moula and Baume Néron present faunal spectra representative of cold and humid occupation phases related to the last glaciation, at the end of MIS 4 and beginning of MIS 3. The main difference with the south-western assemblages is that, with Salzgitter, these assemblages are all associated with a predominantly Levallois production (points and elongated products) with very few or no Quina retouches. At Salzgitter, a Micoquian series including Keilmesser-types is associated moreover with the Levallois debitage (Tode et al. 1953). Thus, it is interesting to note that the model advanced by Delagnes and Rendu (2011) for the south-west, with a Quina system associated with well-planned reindeer exploitation, a discoid-denticulate system reflecting more opportunistic behaviours related to bison or horse hunting and a Levallois technology related to foraging mobility

with no selective hunting, cannot be applied to other regions. Finally, at Abri du Maras, we must underline that part of tool kit production, such as the use of some points used as projectiles, was planned before arriving on the site. This far-sighted lithic behaviour may be related to the planning of reindeer herd slaughtering by Neanderthal groups. However, despite that observation, we do not observe a link as clear as that observed in the south-west between planned monospecific hunting strategies and lithic technologies, adding to the complexity of the scenario.

Conclusion

The integration of multiple analyses undertaken on the faunal assemblages from level 4.1 at Abri du Maras enabled us to define Neanderthal subsistence behaviours at the site within a precise chronological and palaeoenvironmental framework. Pedo-sedimentary facies, charcoal, stable isotope and tooth wear suggest a cool, but moist regional environment, different from what is highlighted by the faunal spectrum alone, i.e. harsher, steppic conditions. The chronological attribution of the level (beginning of the MIS 3 between 40 ± 3 and 46 ± 3 ka, probably between the Heinrich events H5 and H4, cf. Richard et al. 2015) is consistent with the D-O#12 event recorded in the Villars speleothems (Genty et al. 2010), characterised by a woody steppe with a relatively warm and humid climate compared to earlier periods. At Abri du Maras, the almost-exclusive anthropogenic accumulation of the fauna in level 4.1 represents an exceptional framework to interpret human subsistence strategies. Here, the reindeer-dominated assemblage is representative of planned and collective Neanderthal hunting activities during the autumn. The clear monospecific spectrum, associated with seasonal evidence and the selective transport of some carcass portions to the site, points to short-term mass hunting episodes of reindeer herds, not well recognised until now in the south-eastern France for that period. It can be speculated that reindeer were either hunted during their seasonal migrations and they were not present in the region all year round (i.e. they were a *seasonally restricted* resource), or, if they were the sedentary ecotype, they were exploited during their Autumn aggregations when both male and females tend to be in prime condition, in terms of body weight and body fat percentage (i.e. they were a *seasonally selected* resource). Future analyses of materials from the site, such as strontium isotope analysis of reindeer tooth enamel, will provide insights into whether or not the herds targeted by Neanderthals at Abri du Maras were migratory and further illuminate the nature of this assemblage and therefore the main motivations underlying the regular autumnal activities of the human groups in this region.

In addition to the otherwise specialised nature of Neanderthal activities at Abri du Maras, evidence presented

here are also suggestive of more diverse subsistence strategies at the site, for example, the evidence for numerous episodes of fire use and the in situ consumption of meat and marrow. In addition, lithic debitage, woodworking and possibly manufacturing string or nets (Hardy et al. 2013) point to mainly non-specialised activities, possibly evidencing adaptable and diverse seasonal behaviours. This corroborates the regional mobility model that has been previously proposed for this region of south-eastern France, i.e. a far-sighted circulating model very closely associated with regional micro-topography and available seasonal resources (biotopes and raw material outcrops) (Daujeard and Moncel 2010; Daujeard et al. 2016). Many Middle Palaeolithic assemblages with monospecific fauna indicate secondary butchery processing with evidence of food storage and no or scant use of fire, indicating short-term human occupations. At Abri du Maras, we cannot confidently associate short-term hunting episodes with short-term occupations of the site, and one does not necessarily preclude the other. Further investigations combining faunal, lithic and spatial analyses will permit to have a better idea of the type and duration of the human occupations within the level 4.1. Finally, data of the sub-contemporaneous faunal assemblage from level 4.2 will provide precious additional data for understanding fluctuations in Neanderthal subsistence strategies in the same topographical context in a later period and under a different climatic regime.

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Résumé

Appréhender les traditions culturelles au Paléolithique sur la base du registre osseux est encore une approche très peu développée, notamment pour les périodes anciennes. Au Paléolithique moyen, le rapport essentiel des néandertaliens à la graisse, et en particulier à la moelle jaune, a motivé notre intérêt à tester l'existence de pratiques traditionnelles bouchères grâce aux gestes et aux techniques de la fracturation osseuse. L'analyse de la distribution des marques de percussion laissées sur les os longs lors de l'extraction de la moelle dans plusieurs séries du Paléolithique moyen de France (Abri du Maras, Grotte de Saint Marcel) et d'Italie (Riparo Tagliente) montre l'existence probable de pratiques standardisées. En parallèle, nous avons mené une très vaste expérimentation portant sur la part de l'intuitivité dans le procédé d'extraction de la moelle. À l'aide d'une méthode originale d'analyse spatiale appliquée sur les os longs (SIG), cette expérimentation a permis de mettre en évidence des modèles de distribution spécifiques largement contraints par la morphologie des os.

Abstract

The comprehension of cultural traditions during the Paleolithic based on the bone register is still an undeveloped approach, especially for older periods. During the Middle Paleolithic, the essential relationship of Neandertals to fat, particularly to yellow marrow, motivated our interest in testing the existence of traditional butchery practices through the gestures and techniques used to fracture bones. Analysis of the distribution of percussion marks left on long bones during marrow extraction in several series of the Middle Paleolithic from France (Abri du Maras, Saint-Marcel cave) and Italy (Riparo Tagliente) showed that there was probably standardized practices. In parallel, we carried out a very extensive experiment on the role of intuitiveness in the bone marrow extraction process. Using an original spatial analysis method applied to long bones (GIS), this experiment highlighted specific distribution models that were largely constrained by bone morphology.

Riassunto

Comprendere le tradizioni culturali paleolitiche sulla base dei dati osteologici è un aspetto ancora poco sviluppato, soprattutto per i periodi più antichi. Nel Paleolitico medio la stretta relazione dei neandertaliani con il grasso, e in particolare con il midollo giallo, ha stimolato il nostro interesse a verificare l'esistenza di pratiche tradizionali di macellazione mediante l'analisi dei gesti e delle tecniche di fratturazione ossea. Lo studio della distribuzione delle tracce di percussione, prodotte sulle ossa lunghe durante l'estrazione del midollo, in alcune serie del Paleolitico medio francese (Abri du Maras, Grotte de Saint Marcel) e italiano (Riparo Tagliente), rivela la probabile presenza di pratiche standardizzate. Parallelamente, abbiamo condotto un'ampia attività di sperimentazione per stabilire il ruolo dell'intuitività nel processo di estrazione del midollo osseo. Grazie all'applicazione originale dell'analisi spaziale sulle ossa lunghe (GIS), questa sperimentazione ha consentito di evidenziare dei specifici modelli di distribuzione delle tracce, che risultano essere in gran parte vincolati dalla morfologia ossea.