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À la recherche des plumes et des serres de rapaces : résultats d'une approche expérimentale

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Abstract: During the Middle and Upper Palaeolithic periods, several bird species, including raptors, were used by hunter-gatherers for both edible and non-edible products (feathers, claws, bones, tendons, etc.) that could be employed for varying purposes. Bones, the main archaeological evidence of these human-bird interactions, sometimes recorded the memory of our ancestors' handling. Theoretically, the analysis of such traces makes it possible for us to deduce the gestures that were carried out, the intentions behind them, and the products, perishable or not, that were pursued. Nevertheless, interpretations are sometimes difficult due to the lack of a standard reference.

For this article, the removal of wing feathers from 10 thawed raptor carcasses and talons from seven of these specimens provides new qualitative and quantitative data to help fill the gap. The aim is to record the cut marks derived from these actions and associate them with specific practices that our ancestors may have developed. The majority (78%-100%) of the long wing bones, the first phalanges of the major fingers, the penultimate and ungual phalanges of the feet show at least one cut mark. The other wing bones are also affected but in smaller proportions (20%-50%). The orientation of the striae: oblique, transverse or longitudinal, varies depending on the anatomical element. On the humerus, cut marks are located on all portions of the bone and on both the anterior and posterior surfaces. On the other long bones, marks are mainly on the shaft but do also affect the proximal or distal ends. The large quantity of cut marks could be the result of the condition of the carcasses used (thawed and sometimes dehydrated). However, the results obtained provide useful data without contradicting previously published experimental data on a smaller number of specimens. Finally, some comparisons between the experimental and archaeological material allow us to support the proposed interpretations of feather removal and talon extraction by past human communities.
Keywords: zooarchaeology, methodology, actualistic data, experimentation, cut marks.

Résumé : Au cours du Paléolithique moyen et récent, plusieurs espèces d'oiseaux, dont des rapaces, ont été utilisées par les chasseurs-collecteurs et auraient fourni des matières alimentaires et non alimentaires (plumes, griffes, ossements, tendons, etc.). Les ossements qui sont les principaux témoins archéologiques des relations hommes-oiseaux ont parfois enregistré la mémoire de leur manipulation par nos ancêtres. Théoriquement, l'analyse de ces traces permet de déduire, en négatif, les gestes qui furent réalisés, les intentions qui les sous-tendent, et les produits, périssables ou non, qui furent recherchés. Néanmoins, leur interprétation demeure parfois délicate, faute de référentiel suffisant.

Une expérience de prélèvement des plumes de l'aile et de griffes, conduite respectivement sur 10 et 7 carcasses de rapaces décongelées fournit des données qualitatives et quantitatives nouvelles participant à combler ce déficit. La majorité (de 78 % à 100 %) des os longs de l'aile, des premières phalanges du doigt majeur, des pénultièmes phalanges du pied et des serres montre au moins une strie. Les autres ossements de l'aile sont également concernés, mais dans des proportions plus faibles (de 20 % à 50 %). L'orientation des stries, oblique, transversale ou longitudinale est variable selon l'élément anatomique. Sur l'humérus, les groupes de stries se situent sur toutes les portions de l'os en faces antérieure et postérieure. Sur les autres os longs, ils se localisent essentiellement sur le corps sans épargner les articulations. L'importante quantité de stries produites pourrait résulter de l'état des carcasses utilisées (décongelées, déshydratées). Les résultats obtenus enrichissent sans les contredire les données expérimentales précédemment publiées sur un plus petit nombre de

spécimens. Enfin, quelques comparaisons entre le matériel expérimental et archéologique permettent d'asseoir des interprétations proposées quant au prélèvement des plumes et des griffes par les communautés humaines passées.
Mots-clés : archéozoologie, méthodologie, données actualistes, expérimentation, traces de découpe.

INTRODUCTION

Recent discoveries have allowed us to clarify the interest that human communities had in birds during the ancient phases of European history (e.g. Laroulandie, 2004 and 2016; Blasco and Fernández-Peris, 2009; Bochenski et al., 2009; Peresani et al., 2011; Morin and Laroulandie, 2012; Romandini et al., 2014; Radovčić et al., 2015; Fiore et al., 2016; Wertz et al., 2016; Majkić et al., 2017; Hussain, 2019; Goffette et al., 2020). The role of birds within the traditions of the hunter-gatherers of the Middle and Upper Palaeolithic periods has been re-examined and appears more complex than previously perceived (McBrearty and Brooks, 2000; Villa and Roebroeks, 2014). Past human populations appear versatile enough to adapt to different conditions as well as hunt and capture animals for specific purposes. During the Middle and Upper Palaeolithic periods, several bird species were captured and provided edible and non-edible products, such as feathers, talons, long bones or tendons (see Blasco and Peresani, 2016; Gómez-Olivencia et al., 2018 and the references therein). Among them, diurnal and nocturnal raptors held a special place. Diurnal raptors, notably those which are regular or seasonal scavengers, appear to have been attractive to ancient human populations, especially Neanderthals (Finlayson and Finlayson, 2016; Finlayson et al., 2019). Many cases have been discovered in which these large birds were handled for the recovery of meat, feathers or talons used for feeding or symbolic-mediated behaviour (e.g. Fiore et al., 2004; Soressi et al., 2008; Dibble et al., 2009; Peresani et al., 2011, Finlayson et al., 2012; Morin and Laroulandie, 2012; Romandini et al., 2014; Radovčić et al., 2015 and 2020; Laroulandie et al., 2016 and 2020; Majkić et al., 2017; Gala et al., 2018; Gómez-Olivencia et al., 2018; Blasco et al., 2019; Rufà and Laroulandie, 2021). Humans were likely aware of owls before Upper Palaeolithic, a period during which the human-owl interface became more prevalent, a view supported by bones with anthropogenic traces and by representations identified in various contexts (see Hussain, 2021 and the references therein).

The archaeological evidence of these human-raptor interactions is almost exclusively limited to bones, as other materials constituting the bird having succumbed to the effects of time and bird figurations are few (e.g. Nicolau-Guillaumet, 2008; Braun, 2018). At least some of these bones have recorded the memory of our ancestors' handling. Theoretically, an analysis of the traces visible on the surfaces of these remains as well as their anatomical distribution would allow us to deduce, in negative, the gestures that were carried out, the intentions behind them and the products, perishable or not, that were pursued (e.g. Shipman and Rose, 1983; Shipman et al., 1984; Funk et al., 2016; Soulier and Costamagno, 2017; Costamagno et al., 2019a). Although cut marks are one of the most informative elements for documenting human activity, interpretations of these marks are sometimes difficult. Indeed, these accidental marks may be the result of different actions that are not always easy to discern from one another (feather removal, disarticulation, evisceration or defleshing, among others). Some actions carried out by humans on their prey involve comparable gestures. As a consequence, the traces produced during specific actions may be close to others when considering their location, orientation and depth. To overcome this, we must separately and precisely characterise the types of traces that each activity may generate. Experimental archaeology is a helpful tool, as it allows researchers to carry out, in an organised and controlled way, the processes that can be related to certain traces (e.g. Costamagno et al., 2019b). Along this line, a few previous studies were conducted specifically on bird carcasses (Laroulandie, 2001 and 2005; Laroulandie et al., 2008; Romandini et al., 2014 and 2016; Funk et al., 2016; Pedergnana and Blasco, 2016; Val et al., 2016; Blasco et al., 2019; Lloveras et al., 2020).

Some of these studies have already characterised cut-mark patterns on bones from experimentation on raptor carcasses and applied their conclusions to the archaeological record (Laroulandie, 2000; Pedergnana and Blasco, 2016; Romandini et al., 2014 and 2016; Blasco et al., 2019). Experiments are often carried out with only a few specimens, mainly because there are legal restrictions concerning birds of prey. Specimens used for research are obtained through agreements with scientific parks and administrative institutions, which donate animals to research institutions once they die. This makes it difficult to collect a large number of specimens to obtain robust experimental data. Moreover, preservation facilities are not always available to keep the animals in optimal conditions for a long period. Likewise, even if they die naturally or accidentally, strict protocols must be followed when processing animal carcasses (e.g. Winker, 2000). In the past few years, the PACEA Laboratory (UMR 5199, Bordeaux University) has obtained several raptor carcasses to enhance its osteological collection (Lenoble et al., 2019; see note 1). We took this opportunity to process the specimens during experimentation, before entering the skeletons into the collection.

The present work aims to develop an experimental reference framework to better characterise the cut marks resulting from the removal of wing feathers and talons from raptors. Ten carcasses were processed to extract the wing feathers and seven of them were also handled for the talons. Through a few selected cases, we attempted to address the activities with which some of the cut marks observed in the archaeological record may have been associated.

1. MATERIALS AND METHODS

1.1. Specimens

For the present experimentation, we processed 10 carcasses of diurnal and nocturnal raptors of different sizes, duly acquired, to extract the wing feathers still attached to the skin. In other words, 20 wings have been treated (table 1). From these 10 raptors, seven were used for talon extraction (table 1), which comprised 56 pedal digits. Small raptors were excluded from this part of the experiment, as they were not found to be associated with human activities in the archaeological record. All specimens were acquired between 2014 and 2017 following the regulations in place. The specimens were frozen whole as they were acquired and kept within tightly sealed plastic bags to limit dehydration. The animals were taken out of the freezer a day before the experimentation to leave enough time for thawing and to allow the carcasses to resemble their raw states as much as possible.

1.2. Experimental protocols

The carcasses were treated with unretouched silex flakes knapped for this purpose, as they are common tools in the European Palaeolithic record. Over three days, one researcher performed the whole experiment to avoid differences in the treatment of carcasses as well as to see if any variations could be observed between specimens during the feather and talon extractions. The researcher had treated several bird carcasses before this project, and while she could not be called an expert, she was not a beginner either. Since the animals were acquired for incorporation into the PACEA osteological collection, they were handled with the constraint of not breaking the bones. Thus, when removing the wing feathers and talons, we avoided strong mechanical stress that would have affected the bones.

The whole experiment was documented both graphically and by using specific card files prepared for each raptor extremity (right and left wing and foot) to be filled with all the information that came up during the experiment. Photos were taken throughout the whole process and for all the specimens. The cards were filled out with the details of several variables: (a) the time invested for each extremity, (b) the cutting direction concerning the longitudinal axis of the bone (longitudinal, transversal or oblique) and (c) the type of movements performed

Taxon	Inventory number	Wingspan (cm)	Weight (kg)	Feather removal	State	Time (minutes)	Talon extraction	State	Time (minutes)
Gypaetus barbatus	PACEA-O-882	235-265	5.0-7.0	x	Thick skin	52	x	Flexible and soft	24
Aquila nipalensis	PACEA-O-384	175-200	2.7-4.9	x	Rigid and dry	24	x	Rigid and dry	40
Aquila heliaca	PACEA-O-423	190-210	2.5-3.5	x	Rigid	32	x	Rigid	23
Accipiter gentilis	PACEA-O-476	100-120	0.7-1.3	x	Flexible and soft	23	-	-	-
Milvus migrans	PACEA-O-816	113-117	0.7-0.9	x	Flexible and soft	20	-	-	-
Haliaeetus vocifer	PACEA-O-885	190-200	2.0-3.6	x	Flexible and dry	45	x	Flexible and soft	18
Haliaeetus albicilla	PACEA-O-888	210-265	3.6-5.4	x	Rigid and dry	50	x	Rigid and dry	42
Bubo scandiacus	PACEA-O-777	150-160	1.3-2.6	x	Flexible and soft	23	x	Flexible and nervous	21
Bubo bubo	PACEA-O-814	155-180	2.0-3.3	x	Flexible and soft. Ossified tendons	42	x	Rigid and stiff	28
Strix nebulosa	PACEA-O-887	131-142	0.7-1.2	x	Flexible and soft	17	-	-	-

Tabl. 1 – Informations relatives aux spécimens utilisés pour l'expérimentation (numéro d'inventaire de la collection ostéologique de PACEA ; envergure et poids moyen de l'espèce concernée ; prélèvement des plumes et des serres indiqué par un « x » ; description de l'état des extrémités ; durée de la manipulation).

***Table 1** – Data concerning the specimens used for the experiment (inventory number of the PACEA's osteological collection, wingspan and weight average of the species concerned, feathers and talon extraction is indicated with a "x", description of the state of the extremities and handling time).*

(straight, parallel, circular) along with the bones. Other observations, such as the relative flesh adherence to the bone or the rigidity or flexibility of the carcasses at the time of the experiment, have been noted (table 1). Further information on the tools, their morphology and the edges used can be found in C. Martin (2020). These variables were not considered for the current research, which focuses on the location and frequency of cut marks.

The movements made by the researcher on the wings followed similar guidelines for all the specimens (fig. 1). The researcher was standing, and the carcasses were placed on a dissection table. This constraint in the treatment of the birds is linked to compliance with health standards. After choosing a lithic tool, the researcher made semi-circular incisions close to the proximal humerus to separate the wing feathers from the scapular ones. Longitudinal incisions were then made along the medial shaft of the humerus to the distal part.

At the elbow and wrist junctions, where the feathered skin strongly adhered to the bones, several transversal and oblique movements were performed. Longitudinal cuts along the radius-ulna were made to separate the feathered skin from the bones and muscles. Further long and oblique movements were made along the ulna to cut the ligaments attaching the follicles of the secondary remiges (flight feathers) to the quill knobs running along the ulna shaft. Several repeated movements (oblique and longitudinal) had to be done along the carpometacarpus to extract the first remiges within the skin.

We observed in most of the specimens that alula feathers remained attached to the bone. Then, multiple longitudinal cuts up to the phalanges of the major wing digits were made on the dorsal side. Finally, longitudinal incisions were performed down to the wing phalanges to recover all feathers.

The talons were separated at the joints with the penultimate phalanges. At this point, the tissues covering the phalanges were cut at their dorsal and plantar sides. Manual flexion was frequently used to soften the joints and facilitate the cutting of ligaments and tendons. Sometimes, an incision was made on the plantar side at the proximal part of the toe to release the flexor muscle tendons and facilitate the process. After that, the researcher proceeded with semi-circular movements around the articulation to separate the talons.

Once the experiment was completed, we prepared the skeletons for the removal of the main soft tissues, taking care to not affect the bones. The carcasses were dismembered, avoiding direct contact with the bone surface so as to not leave any stigma that could mislead the future reading of the bones. They were then boiled. The long wing bones (humerus, radius, ulna and carpometacarpus) were pierced with a Dremel to clean the inner parts, which were often greasy. The pedal phalanges, after cautiously removing the skin and keratin, were bathed in enzymes for several days to remove any remaining tissue on the bones. After cleaning, the wing bones and pedal phalanges were individualised and identified with a catalogue number made with a calibrate marker.

1.3. Methods of analysis

Once the preparation process was finished, the bones were analysed by using a stereomicroscope (Euromex Nexius Zoom NZ 1902-P) with magnification up to 45× to document all the cut marks observed on the bones (Shipman and Rose, 1983; Domínguez-Rodrigo et al., 2009). For the cut marks produced on the wing bones, there were two specimens that were analysed by the three of us, who then performed a cross validation of observations to reach consensus among all analysts. The same was done for all the pedal phalanges by two of us.

To document and locate the presence of striae on bones, different parameters were considered. Long bones were divided into up to five portions (1: proximal end; 2: proximal shaft; 3: mid-shaft; 4: distal shaft; and 5: distal end) and four faces (anterior, posterior, lateral, medial) to accurately locate the cut marks. The carpometacarpus was divided into three portions, two for the extremities and one for the shaft. Wing phalanges, including the alula, ulnare and radial were not divided into portions, due to their morphology and dimensions, and only the aforementioned faces have been taken into account. Penultimate and ungual phalanges were analysed considering faces (dorsal, plantar, lateral, medial and articulation). For the penultimate phalange, we distinguished between the lateral and the medial articulation (or pulleys). For ungual phalanges, distinctions were made between the *tuberculum flexorium* (TF), the *tuberculum extensorium* (TE), the plantar-medial-lateral edges (PE-ME-LE) and the area under the lateral and medial edge (UL and UM).

Along with location, the distribution of cut-mark groups (isolated or multiple) and their orientation according to the longitudinal axis of the bone (longitudinal, transversal or oblique) were considered. We regard a group of striae as cut marks that apparently result from the same gesture.

2. RESULTS

2.1. Removal of wing feathers

A total of 200 wing bones from 10 individuals and 10 anatomical elements were analysed. Each long bone (humerus, radius, ulna and carpometacarpus), carpal bone (radial and ulnare) and wing phalanx (alula, first and second phalanges of the major digit and phalanx of the minor digit) are represented by 20 pieces. A first analysis of the marks was conducted during a master's thesis (Martin, 2020) and recorded in detail the striations on each bone. In this paper, we focus on global data concerning the number of affected remains by species and by anatomical elements and also the location and orientation of the marks. A dozen unretouched flint tools have been used to remove the feathered skin, some of them employed for several carcasses (Martin, 2020). On ave-

Fig. 1 – Étapes de l'expérimentation de prélèvement des plumes (a à f) et des serres (g à i) : a) mouvements effectués autour de la partie proximale de l'humérus pour séparer les plumes de l'aile des scapulaires ; b) incision le long de l'ulna-radius pour séparer la peau emplumée ; c) apparition de l'ulna durant le prélèvement des plumes de l'aile ; d) découpe des ligaments attachant les régimes secondaires aux apophyses anconales de l'ulna ; e) mouvements effectués au niveau proximal du carpométacarpe pour prélever les rémiges ; f) exemple de peau de l'aile emplumée après prélèvement ; g) incision en face dorsale au niveau de l'articulation pour séparer la griffe de la pénultième phalange ; h) mouvements semi-circulaires autour de l'articulation pour séparer la griffe ; i) incision sur la face plantaire au niveau proximal du doigt pour couper le ligament (clichés A. Rufà ; a, c, e et f : *Bubo bubo* ; b : *Haliaeetus vocifer* ; d : *Gypaetus barbatus* ; g, h et i : *Haliaeetus albicilla*).

***Fig. 1** – Phases of the experimentation process during feather removal (a to f) and talon extraction (g to i): a) Movements around the proximal humerus to separate the wing feathers from the scapular ones; b) Incision along the radius-ulna to separate the feathered skin; c) Exhibition of the ulna during the removal of wing feathers; d) Cutting of the ligaments attaching the secondary remiges to the ulna quill knobs; e) Movements around the proximal carpometacarpus to extract the remiges; f) Example of the feathered wing skin after removal; g) Dorsal incision at the articular joint to separate the talon from the penultimate phalanx; h) Semicircular movements around the articulation to separate the talon; i) Incision on the plantar side at the proximal part of the digit to cut the ligament (photos A. Rufà; a, c, e et f: Bubo bubo; b: Haliaeetus vocifer; d: Gypaetus barbatus; g, h et i: Haliaeetus albicilla).*

rage, the processing time was half an hour by specimen, with extremes between 17 and 52 minutes (table 1).

Two-thirds of the wing bones (n = 131) exhibit at least one cut mark on their surfaces. The black kite (*Milvus migrans*) and the white-tailed eagle (*Haliaeetus albicilla*) presented the highest number of bones with striae, with nearly 80% of the bones (n = 16) being modified. They were closely followed by the bearded vulture (*Gypaetus barbatus*), with a total of 75% cut-marked elements (n = 15). Thirteen bones (*i.e.* 65%) from the steppe eagle (*Aquila nipalensis)* and the great grey owl (*Strix nebulosis*), and 12 bones (*i.e.* 60%) from the northern goshawk (*Accipiter gentilis)*, the eastern imperial eagle (*Aquila heliaca*) and the African fish eagle (*Haliaeetus vocifer*) are also affected. Although the frequency of marked bones for each taxon is always higher than half of the elements, it should be noted that the individuals presenting fewer striae were nocturnal raptors. This includes the Eurasian eagle-owl (*Bubo bubo*) and the snowy owl (*Bubo scandiacus*), whose bones were only 55% touched (n = 11).

However, the result of a Z-test, performed to check if statistical differences existed between the presence of cut marks on diurnal and nocturnal raptor wing bones, was not significant ($Z = 1.39$; $p > 0.05$). Cut-marked bone frequencies did not appear to be linked to raptor size, as the smaller species (*M. migrans* and *A. gentilis*) were affected as much as the larger ones (compared to *H. albicilla* and *H. vocifer*, respectively).

If we consider the cut marks by skeletal elements and among all the taxa, the long bones (humerus, radius, ulna and carpometacarpus) as well as the first phalanges of the major digits, were affected in 90% to 100% of the cases (table 2). The presence of marks on the smaller bones was much less frequent, especially in the case of the minor digit, the radial and the ulnare. The alulas and the second phalanges of the major digits were touched in nearly 50% of the cases (table 2). This difference between long and small bones is highly significant ($Z = 7.47$; $p < 0.01$).

Beyond this general data, we explored what was happening more specifically regarding the location of the striae, considering long bone portions. On the humerus, cut marks were located on the proximal and distal ends and shafts in 65% of cases, although their presence was also important in the mid-shaft or portion 3 (table 2). In the case of the ulna, the marks were preferentially concentrated in the mid-shaft (90% frequency) but also occurred on the proximal and distal shafts (65%). On the contrary, on the radius, the highest frequencies of striae were found in the mid-shaft (70%) and distal shaft (55%) portions, and the rest of the portions were barely affected. For the carpometacarpus, the incidence of cut marks was important since all portions showed values higher than 50% regarding the presence of striae. The cut marks were especially concentrated on the shaft (90%).

The location (table 3) and orientation (table 4) of the cut marks on specific portions and faces varied depending on the bone (fig. 2). On the humeri, cut marks were concentrated on the anterior and posterior faces. The distal end presented more striae, reaching 55% frequency (of the 20 anterior and posterior distal faces considered for the humeri, 11 bore cut marks). These marks, mainly oblique and transversal, were probably produced when the researcher cut the muscular insertions present at the elbow joint and removed the skin and tendons around this area. At the proximal end, cut marks were observed in 45% of the anterior and posterior faces. They were mainly located at the deltoid crest and the head, transversal and oblique to the bone axis. These marks have been associated with repeated movements carried out during the removal of the scapular feathers. Longitudinal, transversal and oblique marks were also produced along the humerus shaft during the removal of skin with tertial remiges and tectrices.

We also observe a few longitudinal and transversal cut marks on the proximal area of the ulnae and radii, at the anterior and posterior sides, reaching less than 25% of the affected faces. Nevertheless, on these bones, the most important number of marks were located along the shaft as a result of the removal of secondary remiges (fig. 2; table 4). These were mainly grouped cut marks and expanded longitudinally, obliquely or transversally. They were mainly located on the anterior shaft of the radii (55%) and the posterior shaft of the ulnae (75% of the affected faces). The radial and ulnare were rarely touched, and only in the case of the posterior ulnare face did the frequency of cut marks reach 25% (five faces marked out of the 20 analysed).

On the carpometacarpi, longitudinal and oblique cut marks were observed and concentrated on the medial and lateral faces of the shaft (65% and 85% of the faces,

Portion	HUM	RAD	ULN	CMC	ALU	MAJ1	MAJ2	MIN	RAL	ULE	%hum	%rad	%uln	%cmc	%alu	%maj1	%maj2	%min	%ral	%ule
Entire bone	20	19	19	19	9	18	10	5	4	8	100	95	95	95	45	90	50	25	20	40
1	13	4	8	12	-	-	-	-	-	-	65	20	40	60	-	-	-	-	-	-
2	13	7	13	18	-	-	-	-	-	-	65	35	65	90	-	-	-	-	-	-
3	12	14	18	10	-	-	-	-	-	-	60	70	90	50	-	-	-	-	-	-
4	13	11	13	-	-	-	-	-	-	-	65	55	65	-	-	-	-	-	-	-
5	13	5	8	-	-	-	-	-	-	-	65	25	40	-	-	-	-	-	-	-

Tabl. 2 – Effectif et pourcentage des portions touchées par rapport au total des portions analysées pour chaque ossement. La gradation des couleurs indique la quantité – plus ou moins importante – de portions marquées : bleu (très faible : < 20 %), vert (faible : 20,1 % à 40 %) ; jaune (modérée : 40,1 % à 60 %) ; orange (élevée : 60,1 % à 80 %) ; rouge (intense : > 80 %). Hum : humérus ; rad : radius ; uln : ulna ; cmc : carpometacarpe ; alu : alula ; maj1 : première phalange du doigt majeur ; maj2 : seconde phalange du doigt majeur ; min : phalange du doigt mineur ; ral : radial ; ule : ulnaire. Portions pour les os longs : 1. extrémité proximale ; 2. partie proximale du corps ; 3. partie moyenne du corps ; 4. partie distale du corps ; 5. extrémité distale. Portions pour le carpométacarpe : 1. extrémité proximale ; 2. corps ; 3. extrémité distale.

***Table 2** – Number and percentage of touched portions in relation with the total portions analysed for each wing bone. The gradation of colours indicates a greater or lesser amount of marked portions: blue (very low: < 20%); green (low: 20.1% to 40%); yellow (moderate: 40.1% to 60%); orange (high: 60.1% to 80%); red (intense: > 80%). Hum: humerus; rad: radius; uln: ulna; cmc: carpometacarpus; alu: alula; maj1: major digit first phalanx; maj2: major digit second phalanx; min: minor digit phalanx; ral: radial; ule: ulnare. Portions for the long bones: 1. proximal end; 2. proximal shaft; 3. mid-shaft; 4. distal shaft; 5. distal end. Portions for the carpometacarpus: 1. proximal end; 2. shaft; 3. distal end.*

Portion	Faces	HUM marked	%HUM	RAD marked	%RAD	ULN marked	%ULN	CMC marked	%CMC
1	Ant	9	45%	3	15%	5	25%	0	0%
	Post	9	45%	2	10%	5	25%	0	0%
	Med	0	0%	0	0%	0	0%	9	45%
	Lat	0	0%	0	0%	0	0%	7	35%
2	Ant	9	45%	7	35%	6	30%	3	15%
	Post	6	30%	2	10%	7	35%	1	5%
	Med	0	0%	0	0%	2	10%	13	65%
	Lat	0	0%	0	0%	0	0%	17	85%
3	Ant	9	45%	11	55%	6	30%	2	10%
	Post	5	25%	5	25%	15	75%	1	5%
	Med	0	0%	2	10%	4	20%	7	35%
	Lat	1	5%	1	5%	3	15%	3	15%
4	Ant	7	35%	5	25%	8	40%	-	-
	Post	9	45%	7	35%	12	60%	-	-
	Med	0	0%	2	10%	2	10%	-	-
	Lat	1	5%	0	0%	0	0%	-	-
5	Ant	11	55%	4	20%	4	20%	-	-
	Post	11	55%	1	5%	5	25%	-	-
	Med	0	0%	1	5%	0	0%	-	-
	Lat	1	5%	0	0%	0	0%	-	-

Tabl. 3 – Distribution des traces de découpe sur les os allongés de l'aile selon les portions et les faces. Portions pour les os longs : 1. extrémité proximale ; 2. partie proximale du corps ; 3. partie moyenne du corps ; 4. partie distale du corps ; 5. extrémité distale. Portions pour le carpométacarpe : 1. extrémité proximale ; 2. corps ; 3. extrémité distale. Ant : antérieure ; Post : postérieure ; Med : médiale ; Lat : latérale ; HUM : humérus ; RAD : radius ; ULN : ulna ; CMC : carpométacarpe. Les pourcentages ont été calculés en considérant le total des observations pour chaque face de chaque portion (n = 20).

***Table 3** – Distribution of cut marks on elongated wing bones considering the division in portions and faces. Portions for the long bones: 1. proximal end; 2. proximal shaft; 3. mid-shaft; 4. distal shaft; and 5. distal end. Portions for the carpometacarpus: 1. proximal end; 2. shaft; 3. distal end. Ant: anterior; Post: posterior; Med: medial; Lat: lateral; HUM: humerus; RAD: radius; ULN: ulna; CMC: carpometacarpus. The percentages were calculated considering the total number of observations for each side of each portion (n = 20).*

	Groups of oblique striae	% oblique	Groups of longitudinal striae	% longitudinal	Groups of transversal striae	% transversal	Total striae lots
hum	66	57.4	21	18.3	28	24.3	115
rad	38	58.5	11	16.9	16	24.6	65
uln	57	51.4	29	26.1	25	22.5	111
cmc	38	46.9	28	34.6	15	18.5	81
ral	3	60.0	1	20.0	1	20.0	5
ule	7	77.8	1	11.1	1	11.1	9
alu	10	62.5	6	37.5	0	0.0	16
maj1	19	63.3	11	36.7	0	0.0	30
maj2	7	43.8	8	50.0	1	6.3	16
min	4	44.4	5	55.6	0	0.0	9
pen	53	50.5	7	6.7	45	42.9	105
ung	67	67.7	3	3.0	29	29.3	99

Tabl. 4 – Effectif et pourcentage des groupes de stries par élément squelettique selon leur orientation. Hum : humérus ; rad : radius ; uln : ulna ; cmc : carpometacarpe ; alu: alula ; maj1 : première phalange du doigt majeur ; maj2 : seconde phalange du doigt majeur ; min : phalange du doigt mineur ; ral : radial ; ule : ulnaire ; pen : pénultièmes phalanges ; ung : phalanges unguéales.

***Table 4** – Number and percentage of cut mark groups by skeletal element according to their orientation. hum: humerus; rad: radius; uln: ulna; cmc: carpometacarpus; alu: alula; maj1: major digit first phalanx; maj2: major digit second phalanx; min: minor digit; ral: radial; ule: ulnare; pen: penultimate phalanges; ung: ungual phalanges.*

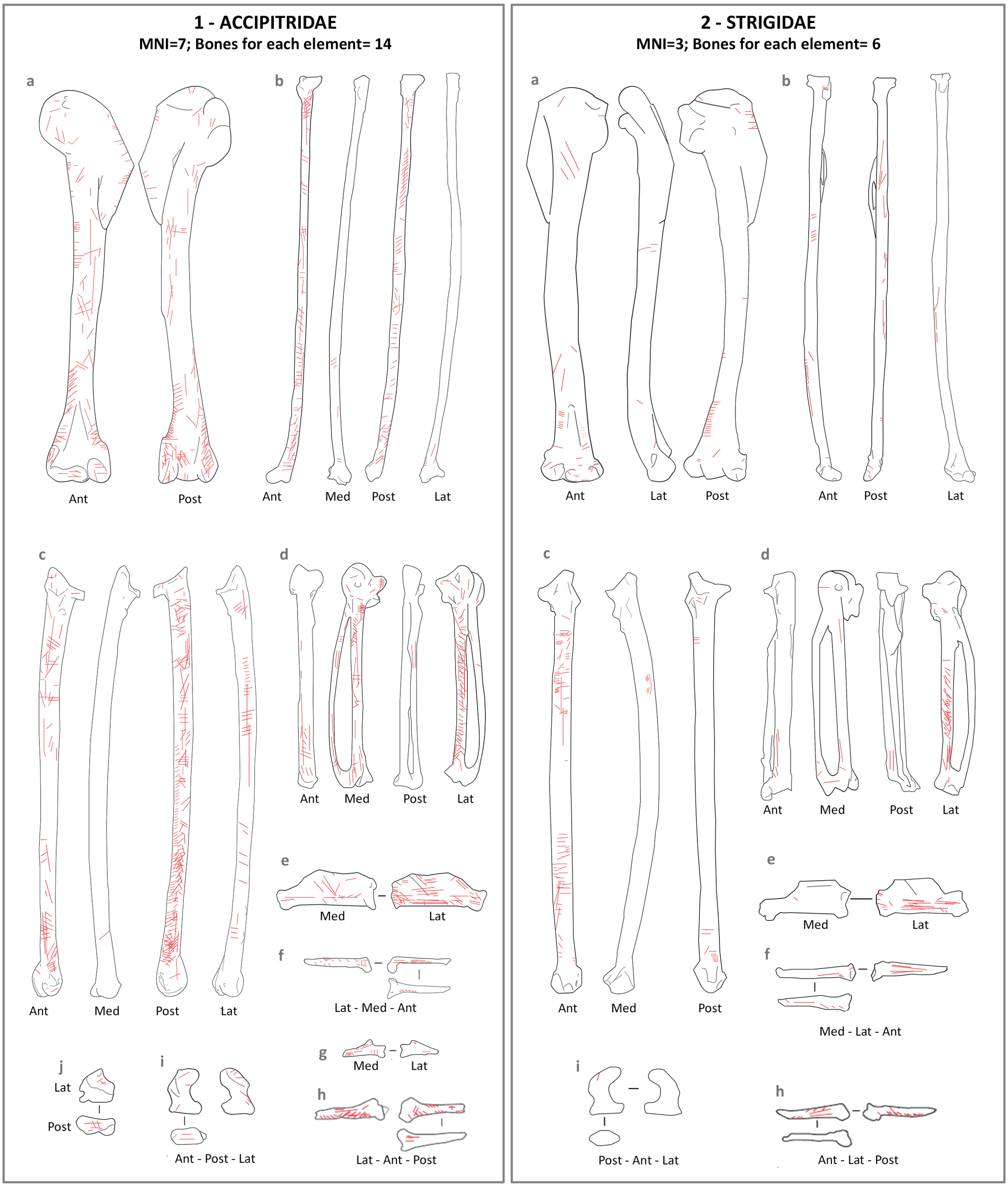

Fig. 2 – Dessins cumulatifs des marques de découpe sur les os des ailes. En raison de la morphologie légèrement différente des os de l'aile, une distinction a été faite entre les Accipitridae (1) et les Strigidae (2). Éléments figurés : a) humérus ; b) radius ; c) ulnas ; d) carpométacarpes ; e) premières phalanges du doigt majeur ; f) secondes phalanges du doigt majeur ; g) phalanges du doigt mineur ; h) alulas ; i) ulnaires ; j) radiaux. Seuls les spécimens d'Accipitridae montrent des marques de découpe sur le doigt mineur (g) et les radiaux (j).

***Fig. 2** – Cumulative drawings of wing bones bearing cut marks. A distinction has been done between Accipitridae (1) and Strigidae (2), as the morphology of the wing is slightly different. Elements referred: a) Humeri; b) Radii; c) Ulnae; d) Carpometacarpi; e) Major digit first phalanges; f) Major digit second phalanges; g) Minor digit phalanges; h) Alulas; i) Ulnari; j) Radials. Only Accipitridae specimens bear cut marks on the minor digit phalanges (g) and radial bones (j).*

respectively). On the medial and lateral faces, the proximal area was also marked in 45% and 35% of the faces, respectively. They were probably caused during the cuts performed at the wrist joint, where the skin is sometimes really adherent to the bone.

The digit bones were frequently marked on the medial and lateral faces. This was the result of the removal of the primary remiges. As a consequence, many longitudinal and oblique cut marks were registered, especially on the first phalanx of the major digit (cut-marked 50% on the medial face and 70% times at the lateral one) and the alula (25% and 30% marked, respectively). The second phalanx of the major digit and the third digit were poorly marked, with values never reaching 20% of the affected faces.

If we analyse the location of striae groups present on each wing bone (table 5), it appears that the humerus and the ulna have the highest concentration of groups of striae (25.3% and 23.9%, respectively). However, if we look at the number of striae groups by skeletal portions (table 5, fig. 2), the most affected portions are the carpometacarpus and the ulna mid-shafts, which comprise, respectively, 9.1% and 8.6% of the total cut-mark groups recorded. The proximal and distal ends of the humerus, the radius mid-shaft and the ulna distal shaft come next. The group of striae on the first phalanx of the major digit of the wing is also important (6.5%).

2.2. Talon extraction

Seven unretouched flint flakes have been used for the disarticulation of the talons from the seven raptors, a single one employed for three individuals. Talon removal took an average of 3 minutes and 30 seconds with extremes between 2 minutes and 5 minutes.

Of the 112 phalanges analysed (56 penultimates and 56 unguals), 90 presented at least one cut mark (80.4%). Of the penultimate phalanges, 78.6% were affected on the distal area (n = 44), and 82.1% of the ungula phalanges were affected (n = 46). The Eurasian eagle-owl (n = 15; 93.8%), the white-tailed eagle (n = 15; 93.8%) and the African fish eagle (n = 13; 81.3%) presented a higher percentage of modified pedal phalanges. All taxa have values over 75% of cut-marked elements, except for the snowy owl (n = 11; 68.8%). Both nocturnal and diurnal raptors seemed to be affected in similar proportions, and no significant differences have been noticed (fig. 3). Nevertheless, if we look at the number of groups of striae produced per species (table 6), it appears that the Eurasian eagle owl, the white-tailed eagle and the steppe eagle were the most concerned with 35, 36 and 40 groups, respectively, while the rest of the taxa never presented more than 25 groups. These three specimens also showed more rigidity and contraction of the digits at the moment of experimentation, which forced the experimenter to stress on certain areas and produce more cut marks.

On the penultimate and ungual phalanges, most striae were oblique and transversal (table 4), while longitudinal cut marks were unusual. This is due to the semi-circular movements performed during the disarticulation process.

On the penultimate, most marks were located on the lateral and medial sides of the pulleys (in 44.6% and 53.6% of the cases, respectively; table 6, fig. 4). They were probably produced during the cutting of the lateral and medial ligaments. Fourteen groups of cut marks were also found on the articular area of the medial pulley (25%). On unguals, most of the cut-mark groups were located on the lateral edge (41.1% of the marked talons), but they were also important on the *tuberculum exten-*

Portion	HUM	RAD	ULN	CMC	ALU	MAJ1	MAJ2	MIN	RAL	ULE	%hum	%rad	%uln	%cmc	%alu	%maj1	%maj2	%min	%ral	%ule
1	20	5	10	16	13	24	13	7	5	8	5.4	1.3	2.7	4.3	3.5	6.5	3.5	1.9	1.3	2.2
2	17	9	15	34	-	-	-	-	-	-	4.6	2.4	4.0	9.1	-	-	-	-	-	-
3	16	22	32	13	-	-	-	-	-	-	4.3	5.9	8.6	3.5	-	-	-	-	-	-
4	18	14	23	-	-	-	-	-	-	-	4.8	3.8	6.2	-	-	-	-	-	-	-
5	23	6	9	-	-	-	-	-	-	-	6.2	1.6	2.4	-	-	-	-	-	-	-
Total	**94**	**56**	**89**	**63**	**13**	**24**	**13**	**7**	**5**	**8**	**25.3**	**15.1**	**23.9**	**16.9**	**3.5**	**6.5**	**3.5**	**1.9**	**1.3**	**2.2**

Tabl. 5 – Effectif et pourcentage des groupes de stries par portion osseuse considérant le total des groupes dans la collection étudiée. La gradation des couleurs indique la quantité – plus ou moins importante – de portions marquées : bleu (très faible : < 2 %), vert (faible : 2,1 % à 4 %) ; jaune (modérée : 4,1 % à 6 %) ; orange (élevée : 6,1 % à 8 %) ; rouge (intense : > 8 %). Hum : humérus ; rad : radius ; uln : ulna ; cmc : carpometacarpe ; alu : alula ; maj1 : première phalange du doigt majeur ; maj2 : seconde phalange du doigt majeur ; min : phalange du doigt mineur ; ral : radial ; ule : ulnaire. Portions pour les os longs : 1. extrémité proximale ; 2. partie proximale du corps ; 3. partie moyenne du corps ; 4. partie distale du corps ; 5. extrémité distale. Portions pour le carpométacarpe : 1. extrémité proximale ; 2. corps ; 3. extrémité distale.

***Table 5** – Number and percentage of groups of striae in each bone portion, considering the total groups represented in the studied collection. The gradation of colours indicates a greater or lesser amount of marked portions: blue (very low: < 2%); green (low: 2.1% to 4%); yellow (moderate: 4.1% to 6%); orange (high: 6.1% to 8%); red (intense: > 8%). Hum: humerus; rad: radius; uln: ulna; cmc: carpometacarpus; alu: alula; maj1: major digit first phalanx; maj2: major digit second phalanx; min: minor digit; ral: radial; ule: ulnare. Portions for the long bones: 1. proximal end; 2. proximal shaft; 3. mid-shaft; 4. distal shaft; and 5. distal end. Portions for the carpometacarpus: 1. proximal end; 2. shaft; 3. distal end.*

PENULTIMATES			UNGUALS		
Area	**Striae groups**	**% cut-marked**	**Area**	**Striae groups**	**% cut-marked**
Lateral pulley	25	44.6	Tuberculum flexorium	14	25.0
Medial pulley	30	53.6	Tuberculum extensorium	17	30.4
Plantar lateral pulley	4	7.1	Dorsal edge	11	19.6
Plantar medial pulley	3	5.4	Lateral edge	23	41.1
Dorsal lateral pulley	5	8.9	Medial edge	17	30.4
Dorsal medial pulley	4	7.1	Plantar edge	16	28.6
Articular lateral pulley	7	12.5	Under lateral edge	6	10.7
Articular medial pulley	14	25.0	Under medial edge	6	10.7

Tabl. 6 – Distribution et pourcentage des groupes de stries sur les phalanges du pied (pénultièmes et unguéales) selon les aires d'intérêt mentionnées en méthodologie.

***Table 6** – Distribution and percentages of cut mark groups on the pedal phalanges (penultimates and unguals) considering the areas of interest mentioned in the methodology.*

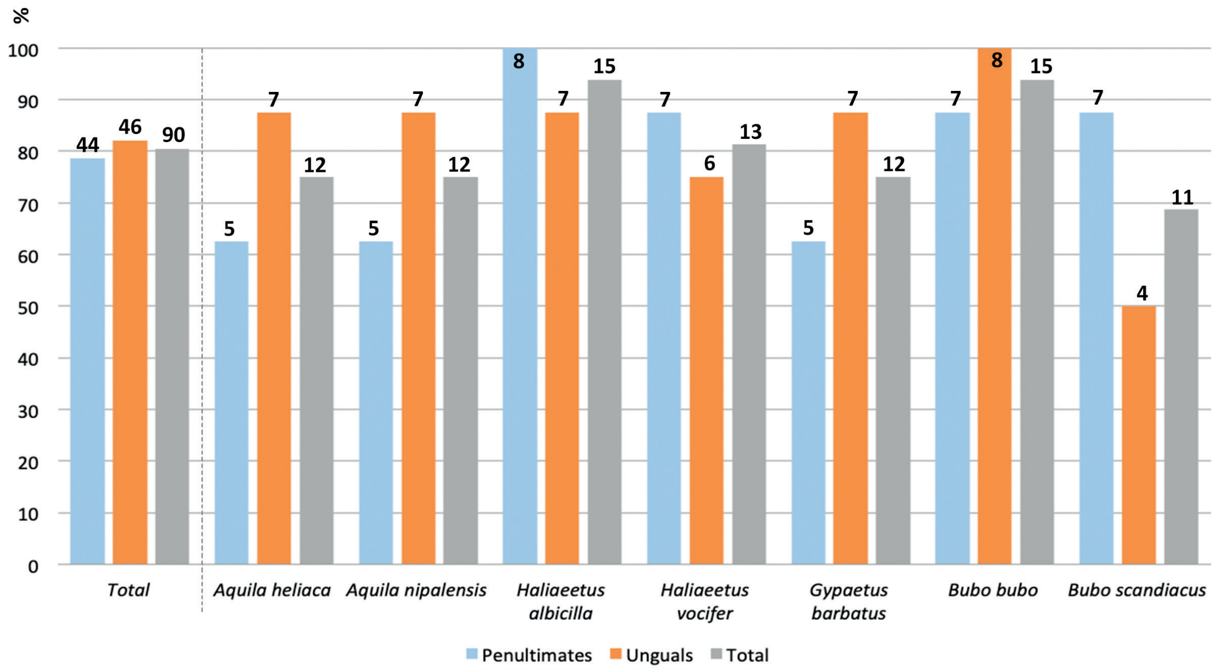

Fig. 3 – Pourcentages et effectifs des phalanges pénultièmes et unguéales portant des marques de découpe, exprimés par taxon. Les trois premières colonnes combinent l'ensemble des spécimens.

***Fig. 3** – Percentage and absolute number of penultimate and ungual phalanges with cut marks, reported by taxa. The first three columns combine all specimens.*

sorium area (30.4%), at the medial edge (30.4%), at the plantar edge (28.2%) and at the *tuberculum flexorium* (25%). No fractures or wrenching associated with flexion of the articulation were noticed.

3. DISCUSSION

The results obtained during our experiment demonstrate that feather removal and talon extraction from raptors lead to an important number of cut marks on bones. All these marks are epiphenomenon in the sense that the handling of the carcasses was carried out not with the intention to leave marks on the bone but to relieve feathered skin and talons. Our results support previous experiments of a comparable nature, displaying comparable conclusions (Romandini et al., 2014 and 2016; Pedergnana and Blasco, 2016; Blasco et al., 2019). Even if some differences can also be highlighted, all the studies agree when registering an important number of striae.

In the case of the wings, all studies concluded that alterations are documented on the humerus, ulna, carpometacarpus, first digit and radial bones (Pedergnana and Blasco, 2016; Romandini et al., 2016; Blasco et al., 2019). According to these previous works, striae tend to

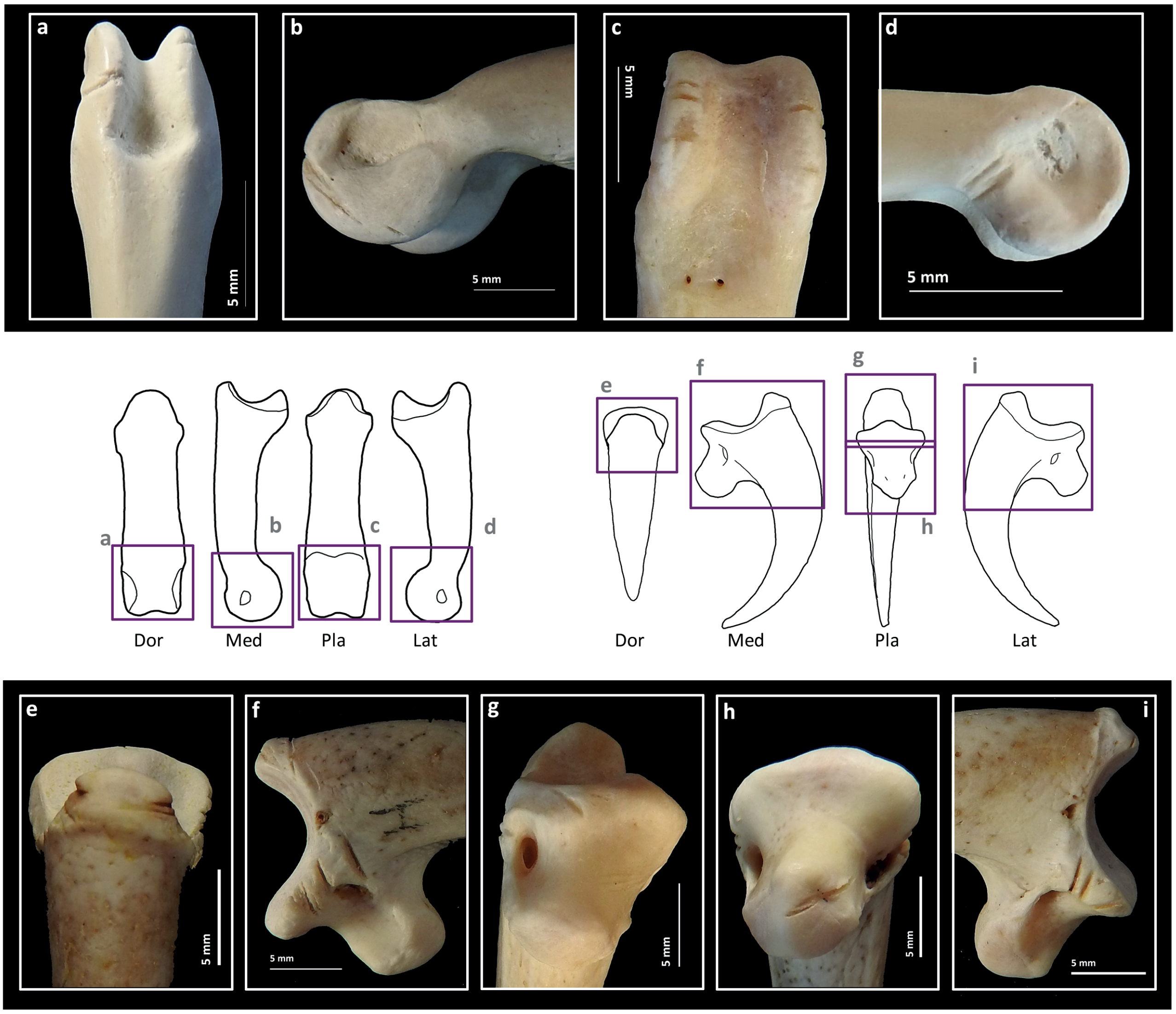

Fig. 4 – Dessins et photographies de phalanges pénultièmes (schéma de gauche et photos a à d) et unguéales (schéma de droite et photos e à i) montrant la localisation des traces de découpe (Dor : dorsale ; Pla : plantaire ; Med : médiale ; Lat : latérale ; clichés A. Rufà ; a : *Bubo bubo* ; b, e, f, h, i : *Heliaeetus albicilla* ; c : *Aquila nipalensis* ; d : *Bubo scandiacus* ; g : *Gypaetus barbatus*).

***Fig. 4** – Drawings and photos of penultimate phalanges (left scheme and images a to d) and ungual phalanges (right scheme and images e to i) showing the location of cut marks (Dor: dorsal; Pla: plantar; Med: medial; Lat: lateral; photos A. Rufà; a: Bubo bubo; b, e, f, h, i: Heliaeetus albicilla; c: Aquila nipalensis; d: Bubo scandiacus; g: Gypaetus barbatus).*

be exhibited on the mid-shaft of the carpometacarpus, ulna and distal humerus, which bears cut marks on its anterior and posterior sides. The results obtained in the current study agree with these findings. In addition, this experiment resulted in some cut marks on the proximal end and shaft of the humerus, which were barely documented in other experiments. In that sense, the way the experimenter intervenes on the wings could influence the results. The previous experiments noted that the ulna and carpometacarpus were the most altered elements (Pedergnana and Blasco, 2016; Blasco et al., 2019), while in the present work, all the long bones of the wing (humerus, radius, ulna, carpometacarpus) exhibit similar proportions of bones bearing cut marks. It is true that, as mentioned by A. Pedergnana and R. Blasco (2016) and R. Blasco and colleagues (2019), the radius shows little alteration in comparison to other bones, but cut marks are still present. Even though longitudinal and oblique marks are the most abundant on the ulna, we also documented some transversal marks.

The differences in the number and orientation of the marks may be due to various reasons. One factor could be related to the number of specimens used for the experiment. In the previous experiments, two to four raptors were used. In the current work, 10 raptors of different species and sizes were processed to document the traces left by the removal of feathers, potentially increasing the variability of the recorded marks.

Unlike other studies (Pedergnana and Blasco, 2016; Blasco et al., 2019), the present work has not found any associated peeling, as the wrist joint has not been stressed with bending to remove feathers. In previous experiments, all the authors agreed that the easiest way to separate the primary remiges from the rest of the wing was to limit the removal of the skin at the wrist joint, separating the carpometacarpi and the phalanges from the rest of the wing. For detachment at the level of the carpometacarpus, manual torsion and bending and incisions with stone tools have to be done, occasionally generating the peeling described by R. Blasco and colleagues (2019). That is also the reason why, in previous experiments, phalanges were barely touched, as the experimenters did not perform any action on that portion when establishing a limit on the carpometacarpus when removing the skin.

On the other hand, according to M. Romandini and colleagues' (2014) results, most of the ungual phalanges displayed multiple traces, and a few penultimate were broken during flexion. According to them, the penultimate and ungual phalanges were very altered, mainly on the medial and lateral sides. For the unguals, no remarkable differences have been detected between the present study and that previous experiment, but we provide more data concerning penultimate phalanges. No breakage was observed in our experiment because of the previously evocated reason.

Apart from the experimental works, the current results match with some of the cut marks observed on the archaeological record, which were interpreted as resulting from gestures produced when removing feathers and extracting talons (e.g. Fiore et al., 2004; Peresani et al., 2011; Finlayson et al., 2012; Morin and Laroulandie, 2012; Romandini et al., 2014 and 2016; Radovčić et al., 2015; Laroulandie, 2016; Laroulandie et al., 2016 and 2020; Romandini, 2017; Mourer-Chauviré, 2019). It should be noted that some cut marks observed on the ulnae and carpometacarpi are very similar to those recorded at the Grotta di Fumane (Italy) and Gorham's and Vanguard caves (Gibraltar; Peresani et al., 2011; Finlayson et al., 2012; Romandini et al., 2016). In these sites, some bones of different large diurnal raptors have been identified, presenting transversal and oblique cut marks at the middle and distal shafts of the wing bones. At the Early Aurignacian levels of Le Piage site (Fajoles, Lot, France), a left ulna from a bearded vulture (*Gypaetus barbatus*) also shows oblique and longitudinal marks, some of them near the *papillae ramigales*, where feathers attach (Laroulandie et al., 2020), which are compatible with the extraction of the feathers from the wing. As a more detailed example, M. Romandini (2017, p. 93, fig. 10) described a cinereous vulture (*Aegypius monachus*) carpometacarpus from the ancient Upper Palaeolithic levels from Grotte de l'Observatoire (Monaco). The remain bears oblique cut marks comparable to those we produced during our experiment. This validates the interpretation proposed by the author of feather retrieval from this large raptor. Other examples come from the Upper Magdalenian sites of Le Morin (Pessac-sur-Dordogne, Gironde; Gourichon, 1994) and Le Bois-Ragot level 5 (Gouex, Vienne; Laroulandie, 2000, p. 223, fig. 85), where several snowy owl carpometacarpi show longitudinal or oblique striations located on the body of the bone that have been attributed to the recovery of the remiges. Once again, our experiment supports this hypothesis.

Beyond raptors, the actualistic data provided may help support hypotheses on the interpretation of cut marks observed on large and medium-size non-raptor birds. For example, the results may be comparable to some wing elements of the alpine chough (*Pyrrhocorax graculus*) and red-billed chough (*Pyrrhocorax pyrrhocorax*) from the Middle Palaeolithic sites of Gibraltar (Finlayson et al., 2012, table S3), a common raven (*Corvus corax*) ulna found in the Upper Magdalenian level 5 of Le Bois-Ragot (Laroulandie, 2000) or a great bustard (*Otis tarda*) carpometacarpus from the Post-Nerian level D of Mandrin (Malataverne, Drôme; Laroulandie, in press; Slimak, 2007), which bear marks that have been attributed to feather removal.

Likewise, regarding talons, the results obtained from the experimentation are comparable with archaeological cases exhibited at Krapina (Croatia), Rio Secco (Italy), Mandrin, Les Fieux (Miers, Lot) and other Middle and Upper Palaeolithic sites (Morin and Laroulandie, 2012; Radovčić et al., 2015; Laroulandie, 2016; Laroulandie et al., 2016; Mourer-Chauviré, 2019). At Krapina, four ungual and pedal phalanges of white-tailed eagle have cut marks, mostly located on the lateral areas of claw articulation and around the *tuberculum flexorium*. A third digit phalanx also bears multiple cut marks on its lateral and dorsal faces (Radovčić et al., 2015). At Rio Secco and Mandrin, a golden eagle ungual phalanx was found in each site that presented transversal and oblique cut marks on their articular areas, at their lateral and medial sides, and at the *tuberculi extensorium* and *flexorium* (Romandini et al., 2014). A terminal phalanx of a golden eagle from Combe-Grenal (Domme, Dordogne) and three white-tailed eagle unguals from Les Fieux levels J base and I and J also exhibit cut marks at the dorsal side of the articulation, above the *tuberculum extensorium* (Morin and Laroulandie, 2012; Laroulandie et al., 2016). These cut marks are similar to those found on ungual phalanges at Fumane and Pech de l'Azé IV (Carsac, Dordogne; Fiore et al., 2004; Dibble et al., 2009). At the above-mentioned site of Le Piage (an ungual phalanx from a bearded vulture exhibits cut marks on the lateral side, at the border of the *condyla articularis* (Laroulandie et al., 2020).

Although the archaeological evidence is clear, it should be noted that the presence of cut marks and their frequency in the archaeological record may vary and do not seem to be as recurrent as observed at the experimental level. One reason is directly related to the level of certainty when determining a cut mark. Experimentally, we can know for sure that a stria is made by the contact of the stone tool with the bone surface, because the bones have not been subjected to other processes that can hinder the diagnosis. In archaeological cases, post-depositional processes may have altered bone surfaces, making the identification of cut marks difficult or questionable (e.g. Domínguez-Rodrigo et al., 2009; Pineda et al., 2014). In many cases, when this occurs, the tendency is to not confirm it as a cut mark, so its documentation would be biased.

In addition, we must consider the possibility that a large number of striations were related to the condition of the carcasses at the time of experimentation. Further experiments should be carried out to test this variable. The fact that raptors are protected species makes it difficult to legally obtain fresh specimens in large quantities. In this context, in addition to the sanitary requirements linked to obtaining these animals, the carcasses are frozen for an extended period. This treatment leads to the dehydration of the specimens, and the tissues are sometimes strongly adhered to the bones in the least fleshy parts, causing rigidity and drying of the tissue. Concerning the freeze-drying process, it can produce skin-tear resistance as well as increased bone fragility (Winker, 2000; Martínez-Vargas et al., 2021). This influences the impact at the time of experimentation, hindering the removal of perishable tissues and forcing the researcher to make extra attempts on the carcasses to cut the skin attached to the bone. Nevertheless, this type of experiment provides us with indications that allow us to associate some of the marks recorded on the bones with the activities carried out by prehistoric populations.

It should also be taken into account that there are some bones, such as the humerus, where the marks found could be related to other butchery activities. Although bones such as the ulna, the radius, the carpometacarpus, or the phalanges do not have meat or have very little meat attached, that could imply other types of action performed on them, other bones such as the humerus still contain meat that could be used by humans, especially in the proximal part. Consequently, when meat is taken from the bones, some traces could overlap with those shown in the present study. Thus, this study aims to help discern these cut marks and identify them more precisely in the archaeological record.

CONCLUSIONS

This work provides new experimental data concerning wing-feathers and talon removal based on the largest number of raptor specimens used to date to address the issue of characterising marks linked to these activities. This allows us to quantify and explore the patterns of the marks. The present work permits the association of some of the cut marks observed on bones with anthropic activities related to the obtaining of wing feathers or talons by human communities. We observed that when feathers are extracted, the humerus is one of the most impacted bones at its distal portion. The ulna, the carpometacarpus and, to a lesser extent, the radius show a high number of cut marks on the shaft. Contrary to previously published studies, some cut marks have been documented on the phalanges of the wing due to differential processing of the carcasses. As far as pedal phalanges are concerned, the modifications produced on the bones indicate similarities with previous experiments and published archaeological cases, which confirms the type of actions that were carried out to obtain the talons.

This work provides important new insights into the interpretation of the marks observed on bones. This not only concerns birds of prey but can be extended to other birds with similar case studies.

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NOTES

(1) https://pacea-collections.inist.fr/collections/show/1

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