



## Article

# New Geometric Morphometric Insights in Digital Taphonomy: Analyses into the Sexual Dimorphism of Felids through Their Tooth Pits

Darío Herranz-Rodrigo <sup>1,2</sup>, Silvia J. Tardáguila-Giacomozzi <sup>1</sup>, Lloyd A. Courtenay <sup>3</sup> , Juan-José Rodríguez-Alba <sup>1</sup>, Antonio Garrucho <sup>4</sup>, Jesús Recuero <sup>4</sup> and José Yravedra <sup>1,2,5,\*</sup> 

<sup>1</sup> Department of Prehistory Ancient History and Archaeology, Universidad Complutense de Madrid, Calle Prof. Aranguren Sn, 28040 Madrid, Spain; dario.herranz.rodrigo@gmail.com (D.H.-R.); silviajt@ucm.es (S.J.T.-G.); juanjorya97@gmail.com (J.-J.R.-A.)

<sup>2</sup> CAI de Arqueometría y Análisis Arqueológico, Universidad Complutense de Madrid, Calle Prof. Aranguren SN, 28949 Madrid, Spain

<sup>3</sup> Department of Cartographic and Terrain Engineering, Higher Polytechnic School of Ávila, University of Salamanca, Hornos Caleros 50, 05003 Ávila, Spain; ladc1995@gmail.com

<sup>4</sup> Departamento Técnico de Animales, Bioparc Fuengirola, C/Camilo Jose Cela 6, 29640 Fuengirola, Spain; agarrucho@bioparcfuengirola.es (A.G.); jrecuero@bioparcfuengirola.es (J.R.)

<sup>5</sup> Grupo de Investigación Ecosistemas Cuaternarios, Facultad de Geológicas Universidad Complutense de Madrid, Calle Prof. Aranguren SN, 28949 Madrid, Spain

\* Correspondence: jyravedra@ucm.es or jyravedra@hotmail.com



**Citation:** Herranz-Rodrigo, D.; Tardáguila-Giacomozzi, S.J.; Courtenay, L.A.; Rodríguez-Alba, J.-J.; Garrucho, A.; Recuero, J.; Yravedra, J. New Geometric Morphometric Insights in Digital Taphonomy: Analyses into the Sexual Dimorphism of Felids through Their Tooth Pits. *Appl. Sci.* **2021**, *11*, 7848. <https://doi.org/10.3390/app11177848>

Academic Editor: Mauro Lo Brutto

Received: 29 July 2021

Accepted: 23 August 2021

Published: 26 August 2021

**Publisher's Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Copyright:** © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

**Featured Application:** The identification of the animal responsible for eating another animal is a complicated topic that has been studied in detail over the years. With the advent of new 3D technologies, as well as the appearance of more advanced statistical approaches, many methods are currently available for the identification of carnivore activities based on their feeding patterns. The present study takes a look at the tooth marks left by tigers and leopards on bone, paying particular attention to the possible differences that may be product of sexual dimorphism. Here tooth pits produced by both male and female tigers and leopards have been studied using geometric morphometrics, revealing the sex of the animal to not be an important conditioning factor in tooth mark shape and size. Furthermore, both leopards and tigers are easily differentiable based on their tooth pits.

**Abstract:** Recent studies using geometric morphometrics for taphonomy have yielded interesting results, opening new horizons of research in both archaeological and paleontological sites. Here we present the analysis of tooth pits left by male and female individuals of two different carnivore species (*Panthera tigris* and *Panthera pardus*) in order to see if sexual dimorphism influences the morphology of tooth pit marks. In the process, 3D-scanning and applied statistics were used. Based on samples derived from two individuals of different sexes, the present results indicate sexual dimorphism in these felid species to not be a conditioning factor of tooth pit morphology.

**Keywords:** neotaphonomy; sexual dimorphism; actualistic studies; geometric morphometrics

## 1. Introduction

In recent years, taphonomic studies applied to the identification and characterization of carnivore intervention and consumption of prey have been reaching a great impulse. Great methodological achievements are being accomplished from an archaeological-paleontological perspective [1,2], with possibilities for further applications in forensic analyses of livestock predation [3].

In archaeological and paleontological contexts, investigation into carnivore activity is typically based on the tooth marks these animals leave on bone. From this perspective,

many authors have specialized in the metric study of these traces [4–6], however, the amount of overlap observed between samples leaves much to be desired when classifying precise carnivore agencies. In modern day ecological contexts, many studies have delved into discerning the carnivores responsible for livestock predation, with methods based on the traces carnivores may leave on skin, meat, or hair [7–10]. Nevertheless, in cases where other scavengers or external processes may have intervened, leaving only the skeletal remains of the carcass, these traces are no longer present.

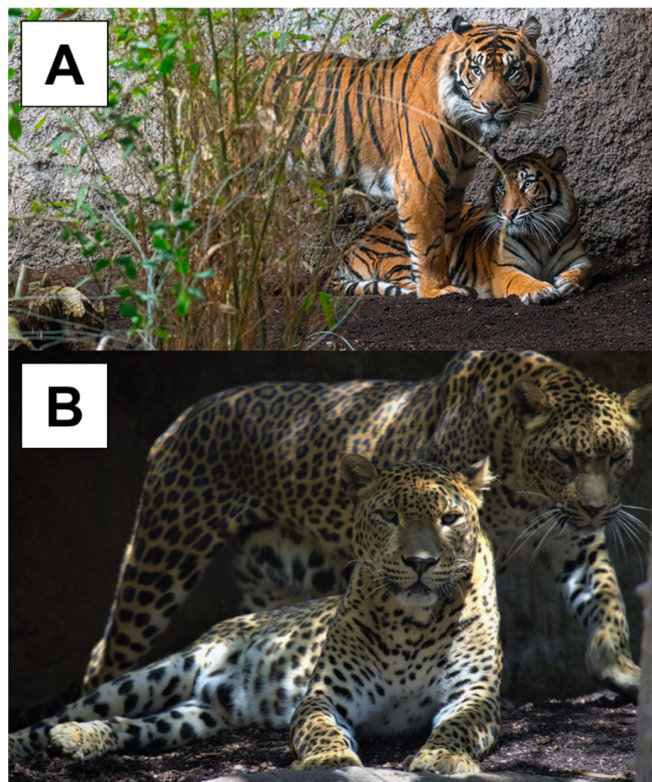
With the integration of more advanced applications in 3D technology and statistics in archaeological and paleontological contexts, [11] and [1] were able to design Geometric Morphometric (GMM) methodological approaches for the characterization of carnivore tooth pits on bone. The application of GMM substituted the traditional descriptive methods for statistical ones allowing the study of size and shape variation, and also allowing for the visualization of resultant covariation in terms of warping and transformation grids, see [12,13]. The GMM has been used frequently in different disciplines in the last 20 years, both in paleontology [14,15], archeology [16,17] and taphonomy [1–3,11,18–20]. Aramendi et al. [1] were able to reveal new insights into the carnivore species that may have intervened in the consumption of hominin fossils dated over 1.7 Mya. Likewise, [2] were also able to identify the activity of felids through tooth marks found on a 1.3 Mya *Paranthropus boisei* fossil from the site of Bell's Korongo (BK, Olduvai, Tanzania).

Since these advances, multiple efforts have been made to increase the resolution of these different approaches, with the added benefit of using computational learning approaches to process such information [3,18–22]. In some of these cases, studies have been able to reach a resolution of correctly identifying the carnivore producing tooth marks with up to >90% accuracy based on their shape and size. These surprising results are not only able to efficiently differentiate between hyenid, felid, canid and ursid tooth marks [21], but also discriminate between species of the same taxonomic family, such as wolves and dogs [3].

Within this line of research, however, a number of questions still remain regarding possible conditioning variables that may distort these results. From this perspective, intraspecific analyses are becoming increasingly important, such as (1) the comparison of tooth marks found on different sized animals [19]; (2) possible intraspecific variability influenced by multiple individuals [22]; (3) or the reliability of experimental samples obtained by animals in captivity or in the wild [22]. In each of these cases, these kinds of queries are valuable since almost all tooth mark-related research is carried out on specific groups of individuals, without taking into consideration the possible variations that may occur when sampling from other populations. In the case where intraspecific variability is a considerable factor, then extrapolation to larger studies is much more difficult. Likewise, most tooth mark samples are developed on preys of a certain size, while animals in captivity have been observed to present different behavioral attributes to wild animals [23–25], thus affecting their tooth mark morphologies [22].

In each of the aforementioned analyses, observations made by authors tend to agree that intraspecific variability from different populations are less likely to affect tooth pits [21,22], at least in the case of wolves. To continue with this line of research, however, it is important that these results be observed equally in other carnivore families, such as felids, to extrapolate information on a larger scale. A recent study by Toledo et al. [26] revealed metric differences in the bite of female and male wolves on dental wax, while noting metric differences mainly in the size of male and female wolf teeth. While other studies have not yet noticed whether sexual dimorphism has an effect on the tooth marks produced [21,22], the sex of these individuals have not been directly observed. The present study considers the possible differences that may be produced by sexual dimorphism, specifically among felid individuals. Felids are well known for their anatomical and physiological differences among males and females [27–29]. Under this premise, if sexual dimorphism does not affect the tooth mark morphologies produced by felid individuals, then carnivores with much smaller dimorphic traits are equally less likely to present differ-

ences. For this purpose, the present study has paid particular attention to the tooth marks produced by male and female leopards (*Panthera pardus kotiya* Deraniyagala, 1956) and tigers (*Panthera tigris sondaica* Temminck, 1844) (Figure 1), two animals with great sexual dimorphism [27,29–31].



**Figure 1.** Male and female (A) tigers and (B) leopards from Fuengirola’s Biopark (image courtesy of Bioparc Fuengirola).

*Panthera tigris sondaica* [30] is a subspecies of tiger that ranges between 100–140 kg for males, while females typically range between 75–110 kg [31]. This implies a marked sexual dimorphism in terms of size, weight, and cranial dimensions, with males having larger and robust skulls [28]. In the case of tigers, dimorphism oscillates between populations, with greater differences existing in tigers originating from areas of higher latitudes [32]. Among skull features, the most dimorphic part is the snout [28].

*Panthera pardus kotiya* is a subspecies of leopard that ranges between 29 kg for females and 56 kg for males. Despite this, some specimens can reach up to 100 kg, varying depending on the environment [27,31]. While skulls of both sexes are morphologically similar, they can present variable sizes [29]. Some scholars suggest that the differences in the craniodental dimension of both sexes, along with the size of the animal, could suggest different eating habits [33].

## 2. Materials and Methods

### 2.1. Sample

The characteristics of carnivores used for this research are provided in Figure 1. In this case, the male individual of *Panthera tigris* studied weighed 120.0 kg and the female 86.2 kg. With respect to *Panthera pardus*, the male, 43.0 kg, is slightly larger than the female, 39.9 kg.

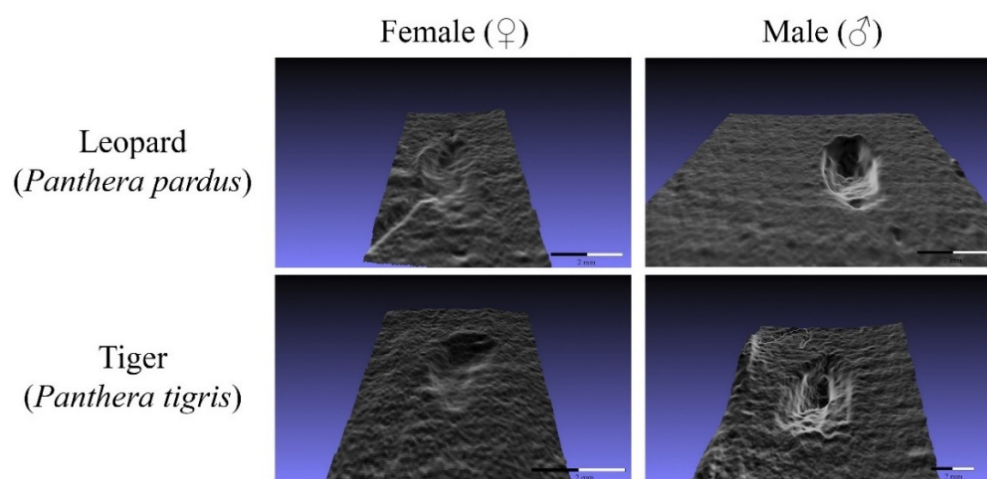
A total of 200 carnivore tooth pits were included and compared in this study; 104 pits produced by tigers (*Panthera tigris sondaica*, Figure 1A: Female = 50; Male = 54), and 96 by leopards (*Panthera pardus kotiya*, Figure 1B: Female = 44; Male = 52).

Both samples originated from the Biopark zoo located in Fuengirola, Málaga (<https://www.bioparcfuengirola.es/animales/>). Both samples were therefore obtained from

carnivores in captivity. No animals were sacrificed solely for the purpose of this study, so all the ethical standards regarding the treatment of animals for experimental purposes were followed. The experimental protocols employed consisted of the collection of bovine ribs with tissue, meat and articulated with vertebrae provided to each of the carnivores during weekly feeding over the course of 2 months. To ensure that samples were not contaminated, female and male individuals were clearly separated during feeding, while the bones recovered were differentiated and labelled accordingly. The bones were cleaned by boiling the sample with water.

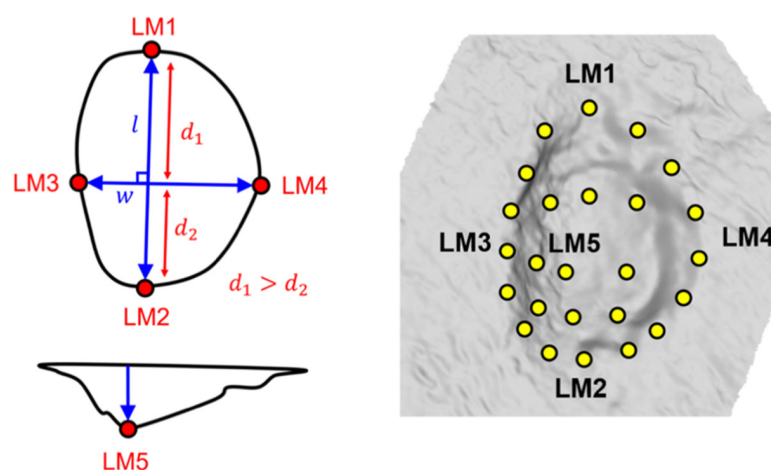
## 2.2. Methods

Structured Light Surface Scanning (SLS) was chosen for all digitization of carnivore tooth marks, using the DAVID SLS-3 located at the Archaeometry unit of the Centre of Assistance for Investigation (CAI) in the Complutense University (Madrid). Models were captured as meshed point clouds in .ply format (Figure 2), which could later be processed using different software for landmark collection.



**Figure 2.** Example of 3D models obtained for male and female tooth pits.

The present study used a 3D 30-landmark model proposed by [19,20]. This model consists of 5 fixed Type II landmarks marking the maximal length, width, and depth of tooth marks, followed by 25 computational landmarks projected across the entirety of the tooth pit using a patch (Figure 3). Landmarking procedures employed the use of the free IDAV Landmark 3.0.0.6 editor software. Landmarks were then formatted into morphological files for further processing using the R programming language (v.4.0.).



**Figure 3.** Visual description of landmark coordinate positions. The positioning of fixed landmarks is



dependent on the perpendicular axes that mark the maximum length ( $l$ ) and width ( $w$ ) of the pit, with Landmark 1 (LM1) being positioned furthest away from  $w$ , such that distance 1 ( $d_1$ ) is greater than  $d_2$ . LM5 marks the deepest point of the pit, without necessarily being the centroid. Computational landmarks (marked in yellow) are then projected across the entirety of the pit, capturing both morphology and depth.

### 2.3. Data Analysis

Landmark data was first standardized through a Generalized Procrustes Analysis (GPA) [34,35]. GPA is an effective means of extracting morphological data quantitatively, allowing for the characterization of *shape* and *form* patterns across different configurations (orientation, translation, and scaling) [36,37]. Before any further hypothesis testing, allometric analyses were first considered to evaluate the impact that the tooth pit size might have had on the morphological variance. To achieve this aim, the logarithm of centroid sizes was calculated and used to perform regression on shape variables [38]. In case shape–size relationships proved to be of importance, final superimpositions were performed excluding the scaling step of the GPA procedure (otherwise known as *form*).

After normalizing, landmark coordinates were processed using dimensionally reduction in the form of Principal Component Analysis (PCA). PCA is a common visualization technique used to assess patterns in morphological trends. Each of these graphs were coupled with the computation of Thin Plate Splines [36,39] to visualize and assess these variations across each PC score. The PC scores representing the highest morphological variability (<95%) were then extracted for further processing.

The degree of statistical differences and similarities between samples was assessed using Two-One Sided equivalency Tests (TOST). This test assesses the magnitude of equivalency between samples according to Cohen's  $\delta$  [40]. For parametric versions of TOST, Welch's  $t$ -statistic was used [41]. In cases where non-parametric tests were needed, the Yuen trimmed robust  $t$ -statistic was used [42,43]. It is important to note that, contrary to many other analyses of variance, both variants of TOST consider the Null Hypothesis ( $H_0$ ) to indicate differences between samples.

Results of statistical hypothesis tests were additionally evaluated considering values of  $p < 0.003$  (i.e.,  $p < 3\sigma$ ) to be a robust indicator of notable differences between samples [21,22,44,45].  $p$ -values accompanied by calculations of their False Positive Risk (FPR) [45] supported this. FPR values are used to assess the probability that an observed  $p$ -value is a false positive, otherwise known as a Type I statistical error [45]. For FPR calculations a prior probability of 0.5 was adopted, assuming complete randomness [45].

The R programming language (v.4.0) was used to perform all statistics.

According to [22], we excluded the tooth scores from this analysis because this type of tooth mark shows intraspecific variability, and additional analysis is needed to evaluate the resolution of this type of tooth mark between the carnivores in captivity.

## 3. Results

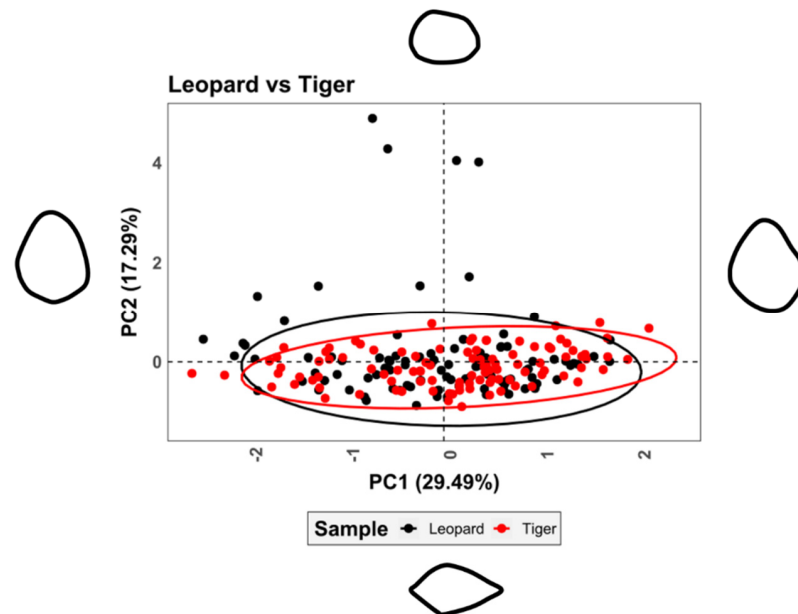
In Table 1, both samples of tigers and leopards are described by non-allometric patterns, with the closest values resembling possible notable differences occurring when comparing species. Interestingly, and contrary to what would typically be expected in species of high sexual dimorphism, notable shape–size relationships are absent when comparing male and female animals. This is especially evident in the case of tigers, an animal presenting considerable size differences.

Geometric Morphometric analyses in shape space produced a principal component analysis represented by 90 PC scores, of which the first 11 represent up to 95% of the total sample variability (Figure 4). As can be seen, great overlap can generally be seen among samples, especially when comparing sexes (Figure 5). In general, both leopard and lions appear to present relatively “long” and “thin” pits, with leopards presenting a slightly stronger tendency towards more oval-shaped pits (PC2 = 17.29% of variance). Nevertheless,

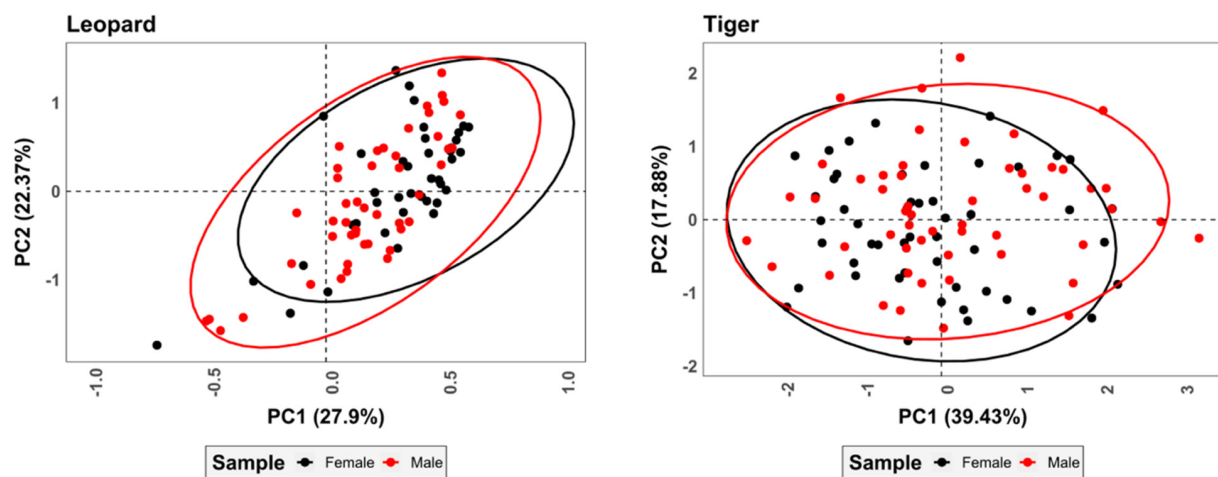
TOST equivalency testing revealed notable similarities between most samples, with the greatest differences appearing when comparing between species (Table 2).

**Table 1.** Results from allometric testing for each of the comparisons and their correspondent FPR value. Res.<sup>2</sup> = Squared residuals. FPR = False Positive Risk. M = Male. F = Female.

Groups Compared	F	Res. <sup>2</sup>	p-Value	FPR
Tiger vs. Leopard	2.7	0.013	0.014	14.0%
Tiger (M vs. F)	1.5	0.014	0.183	45.7%
Leopard (M vs. F)	3.0	0.024	0.045	27.5%



**Figure 4.** Scatterplot presenting the principal component analyses in shape space of tiger and leopard pits. Variances of morphologies are presented in the corner of each axis.



**Figure 5.** Scatterplot presenting the principal component analyses in shape space of tiger and leopard pits when comparing between sexes.

**Table 2.** Equivalency testing values for the different comparisons and their corresponding False Positive Risk (FPR) values. M = Male. F = Female.

Groups Compared	<i>p</i> -Value	FPR
Tiger vs. Leopard	0.042 <sup>1</sup>	26.6%
Tiger (M vs. F)	0.003	4.5%
Leopard (M vs. F)	0.009	10.2%

<sup>1</sup> Test results using non-parametric testing.

#### 4. Discussion and Conclusions

The results obtained highlight aspects and inferences that might be relevant not only for archeology but also for sub-disciplines associated with zoology and applied taphonomy.

To begin, we see how the TOST test has determined that differences are likely to exist between leopards and tigers. At least, according to the present data, the odds of tiger and leopard pits being similar are at most 1 to 2.8 [44], and thus, with a prior probability of 0.5, these odds can be calculated at 1 to 1.4. Considering how other studies have shown high likelihoods of being able to differentiate between large and small felid species [21], the present data are not surprising because [21] was able to differentiate the pits tooth of leopards, lions, and jaguars, and in this work, we have been able to differentiate the pits tooth of leopards and tigers. Alongside other observations made by authors differentiating between carnivore species [3,18,22,46], we could even propose a more optimistic prior probability of 0.75 to report the posterior likelihood of tiger and leopard tooth pits being similar at 1 to 2 [44]. In either case, the present study supports that differentiation between carnivore species is possible.

Regarding the differentiation by sex, TOST values for both intraspecific comparisons affirm that in this sample there are no clear intraspecific differences between male and female samples based on their tooth pits. It should be noted that given the lack of an allometry study in the sample, we are comparing all of them only using the *shape* variable, and not the *form* variable, as in previous studies [18–22]. Despite this, and even if these tests were to be performed on *form* variables, leopards ( $p = 0.009$ , FPR = 10.3%) and tigers ( $p = 0.003$ , FPR = 4.5%) can be calculated to be similar in the *form* space as well.

These results support that the intraspecific size differences of a carnivore, either due to the population variability of the species or due to their sexual dimorphism [27,29,31], do not seem to be a conditioning factor in tooth pit morphology. Furthermore, considering how this has been confirmed in species presenting large sexual dimorphism, the present study strongly implies that tooth marks made by other species, such as those from the canid and hyenid families, may be less likely to be influenced by this variable.

The present study builds on hypotheses proposed by [19,20,22], in that carnivore tooth pits appear to be the type of tooth mark less affected by intraspecific variability, captive stress, prey size, and now sexual dimorphism. In light of this, it can additionally be argued that the results obtained by [1,3,18,22] are reliable for the discerning of carnivore agencies. This is yet another piece to the puzzle that argues that the biomechanical and tooth size variability that are often present [20,27] are not likely to distort these results.

These are promising results that provide a stronger basis for the wider application of our methodological approaches in paleontological, archaeological, and forensic veterinary fields, as well as modern-day ecological studies.

However, the results presented in this work must be taken with caution, since they have been obtained from a small sample and therefore the sample should be expanded in future studies. Despite this limitation, it must be assessed that different carnivores do not show intraspecific variability in tooth pits. Wolves do not show differences in tooth pits between different populations, and neither do leopards and tigers.

**Author Contributions:** Conceptualization, J.Y.; methodology, L.A.C.; validation, L.A.C. and J.Y.; formal analysis, D.H.-R., S.J.T.-G., J.Y. and J.-J.R.-A.; investigation, J.Y. and J.-J.R.-A.; resources, J.Y.; data curation, D.H.-R., S.J.T.-G., A.G. and J.R.; writing—original draft preparation, J.Y., D.H.-R.;

writing—review and editing, D.H.-R., J.Y., S.J.T.-G., L.A.C. and J.-J.R.-A.; visualization, L.A.C., A.G. and J.R.; supervision, A.G., J.Y. and L.A.C.; project administration, J.Y.; funding acquisition, J.Y. All authors have read and agreed to the published version of the manuscript.

**Funding:** L.A.C. is supported by the Spanish Ministry of Science, Innovation and Universities with a FPI Predoctoral Grant (Ref. PRE2019-089411) associated to project RTI2018-099850-B-I00 and the University of Salamanca. D.H.R. is supported by the Ministry of Science, Innovation and Universities, as part of the i+D+I Garantía Juvenil programme (Ref. PEJ2019-005420-A). The present research was additionally supported by the Palarq foundation (Ref. PR2004\_19/01), under project “Dilucidando la acción de carnívoros en los yacimientos del Pleistoceno Inferior Ibérico del Pontón de la Oliva (Madrid), y de Fuente Nueva III y Venta Micena 3 y 4 (Granada)”, 2019–2020 call for funding. Funders had no role in study design, data collection and analysis, decision to publish or preparation of the manuscript.

**Institutional Review Board Statement:** Ethical review and approval were waived for this study due to the fact that no animals were sacrificed specifically to carry out these experiments.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Data used to create the reported results will be made available upon request to J.Y. (joyravedra@hotmail.com) and L.A.C. (ladc1995@gmail.com).

**Acknowledgments:** First, we would like to thank M.A. Maté-González for inviting our contribution to this special edition. We would like to acknowledge the efforts of the staff at the Fuengirola’s Biopark for providing access to samples used in our experiments, and for the pictures of carnivores. We would also like to recognize the technical support provided by C.A.I. Arqueometry and Archaeological Analysis from the Complutense University which has been very useful in carrying out the present paper. We would also like to extend our gratitude to the TIDOP research group of the University of Salamanca, for their comments and support. We would like to acknowledge the support of the PALARQ foundation. Finally, we would like to thank the anonymous reviewer.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Aramendi, J.; Maté-González, M.A.; Yravedra, J.; Cruz-Ortega, M.; Arriaza, M.A.; González-Aguilera, D.; Baquedano, E.; Domínguez-Rodrigo, M. Discerning carnivore agency through the three-dimensional study of tooth pits: Revisiting crocodile feeding behaviour at FLK-Zinj and FLK NN3 (Olduvai Gorge, Tanzania). *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **2017**, *488*, 93–102. [CrossRef]
2. Aramendi, J.; Arriaza, M.A.; Yravedra, J.; Maté-González, M.A.; Ortega, M.C.; Courteany, L.; González-Aguilera, D.; Gidna, A.; Mabulla, A.; Baquedano, E.; et al. Who ate OH80 (Olduvai Gorge, Tanzania)? A geometric-morphometric analysis of surface bone modifications of a *Paranthropus boisei* skeleton. *Quat. Int.* **2019**, *517*, 118–130. [CrossRef]
3. Yravedra, J.; Maté-González, M.A.; Courtenay, L.A.; González-Aguilera, D.; Fernández-Fernández, M. The use of canid tooth marks on bone for the identification of livestock predation. *Sci. Rep.* **2019**, *9*, 16301. [CrossRef] [PubMed]
4. Selvaggio, M.M.; Wilder, J. Identifying the involvement of multiple carnivore taxa with archaeological bone assemblages. *JASR* **2001**, *28*, 465–470. [CrossRef]
5. Delaney-Rivera, C.; Plummer, T.W.; Hodgson, J.A.; Forrest, F.; Hertel, F.; Oliver, J.S. Pits and pitfalls: Taxonomic variability and patterning in tooth mark dimensions. *JASR* **2009**, *36*, 2597–2608. [CrossRef]
6. Andres, M.; Gidna, A.; Yravedra, J.; Domínguez-Rodrigo, M. A study of dimensional differences of tooth marks (pits and scores) on bones modified by small and large carnivores. *Archaeol. Anthropol. Sci.* **2012**, *4*, 209–219. [CrossRef]
7. Mackay, A. *Mitigating Cattle Losses Caused by Wild Predators in British Columbia. A Field Guide for Ranchers*; Ministry of Agriculture & Lands, Agriculture et Agroalimentaire British Columbia Canada, 2005; Available online: [https://www.cattlemen.bc.ca/docs/mitigating\\_cattle\\_losses\\_a\\_field\\_guide\\_for\\_ranchers\\_smaller\\_file.pdf](https://www.cattlemen.bc.ca/docs/mitigating_cattle_losses_a_field_guide_for_ranchers_smaller_file.pdf) (accessed on 25 August 2021).
8. Carmichael, E.J. Targeted Predator Control. A Guide for Livestock Producers on Option Available for Targeted Predator Control. B. C. Agricultural Research & Development Corporation Wild Predator Loss Prevention Pilot Project. 2011. Available online: <https://www.researchgate.net/deref/https%3A%2F%2Fwww.bcac.bc.ca%2Fsites%2Fbcac.localhost%2Ffiles%2FTargeted%2520Predator%2520Control.pdf> (accessed on 25 August 2021).
9. Caniglia, R.; Fabbri, E.; Mastrogiuseppe, L.; Randi, E. Who is who? Identification of livestock predators using forensic genetic approaches. *Forensic Sci. Int. Genet.* **2013**, *7*, 397–404. [CrossRef]
10. Toledo, V.; Ortega-Ojeda, F.; Fonseca, G.; García-Ruiz, C.; Pérez-Lloret, P. Analysis of tooth mark patterns on bone remains caused by wolves (*Canis lupus*) and domestic dogs (*Canis lupus familiaris*) for taxonomic identification: A scoping review focused on their value as a forensic tool. *Appl. Anim. Behav. Sci.* **2021**, *240*, 105356. [CrossRef]



11. Yravedra, J.; García-Vargas, E.; Maté-González, M.A.; Aramendi, J.; Palomeque-González, J.F.; Vallés-Iriso, J.; Matesanz-Vicente, J.; González-Aguilera, D.; Domínguez-Rodrigo, M. The use of Micro-Photogrammetry and Geometric Morphometrics for identifying carnivore agency in bone assemblages. *JASR* **2017**, *14*, 106–115. [\[CrossRef\]](#)
12. Rohlf, F.J.; Marcus, L.F. A revolution in Morphometrics. *Trends Ecol. Evol.* **1993**, *8*, 129–132. [\[CrossRef\]](#)
13. Slice, D.E. Modern Morphometrics. In *Modern Morphometrics in Physical Anthropology*; Slice, D.E., Ed.; Kluwer Press: New York, NY, USA, 2005.
14. Bruner, E. Geometric morphometrics and paleoneurology: Brain shape evolution in the genus Homo. *J. Hum. Evol.* **2004**, *47*, 279–303. [\[CrossRef\]](#) [\[PubMed\]](#)
15. Cobb, S.N.; O'Higgins, P. Hominins do not share a common postnatal facial ontogenetic shape trajectory. *J. Exp. Zool.* **2004**, *302B*, 302–321. [\[CrossRef\]](#) [\[PubMed\]](#)
16. Buchanan, B.; Collard, M. A geometric morphometrics-based assessment of bladeshape differences among Paleoindian projectile point types from western North America. *J. Archaeol. Sci.* **2010**, *37*, 350–359. [\[CrossRef\]](#)
17. Lycett, A.J.; von Cramon-Taubadel, N.; Gowlett, J.A. A comparative 3D geometric morphometric analysis of Victoria west cores: Implications for the origins of Levallois technology. *J. Archaeol. Sci.* **2010**, *37*, 1110–1117. [\[CrossRef\]](#)
18. Courtenay, L.A.; Yravedra, J.; Huguet, R.; Aramendi, J.; Maté-González, M.A.; González-Aguilera, D.; Arriaza, M.C. Combining machine learning algorithms and geometric morphometrics: A study of carnivore tooth marks. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **2019**, *522*, 28–39. [\[CrossRef\]](#)
19. Courtenay, L.A.; Yravedra, J.; Maté-González, M.A.; Vázquez-Rodríguez, J.M.; Fernández-Fernández, M.; González-Aguilera, D. The effects of prey size on carnivore tooth mark morphologies on bone; the case study of *Canis lupus signatus*. *Hist. Biol.* **2020**, 1–13. [\[CrossRef\]](#)
20. Courtenay, L.A.; Herranz-Rodrigo, D.; Huguet, R.; Maté-González, M.A.; González-Aguilera, D.; Yravedra, J. Obtaining new resolutions in carnivore tooth pit morphological analyses: A methodological update for digital taphonomy. *PLoS ONE* **2020**, *15*, e0240328. [\[CrossRef\]](#) [\[PubMed\]](#)
21. Courtenay, L.A.; Herranz-Rodrigo, D.; González-Aguilera, D.; Yravedra, J. Developments in data science solutions for carnivore tooth pit classification. *Sci. Rep.* **2021**, *11*, 10209. [\[CrossRef\]](#) [\[PubMed\]](#)
22. Courtenay, L.A.; Herranz-Rodrigo, D.; Yravedra, J.; Vázquez-Rodríguez, J.; Huguet, R.; Barja, I.; Maté-González, M.A.; Fernández, M.; González-Aguilera, D. Effects of captivity on carnivore mastication implications in ecological studies of both the past and present. *Animals* **2021**, *11*, 2323. [\[CrossRef\]](#)
23. Gidna, A.; Yravedra, J.; Domínguez-Rodrigo, M. A cautionary note on the use of captive carnivores to model wild predator behavior: A comparison of bone modification patterns on long bones by captive and wild lions. *JASR* **2013**, *40*, 1903–1910. [\[CrossRef\]](#)
24. Sala, N.; Arsuaga, J.L.; Haynes, G. Taphonomic comparison of bone modifications caused by wild and captive wolves (*Canis lupus*). *Quat. Int.* **2014**, *330*, 126–135. [\[CrossRef\]](#)
25. Kaufmann, C.A.; Rafuse, D.; González, M.E.; Álvarez, M.C.; Massigoge, A.; Scheifler, N.A.; Gutiérrez, M.A. Carcass utilization and bone modifications on guanaco killed by puma in northern Patagonia, Argentina. *Quat. Int.* **2018**, *466 Pt B*, 165–177. [\[CrossRef\]](#)
26. Toledo González, V.; Ortega Ojeda, F.; Fonseca, G.M.; García-Ruiz, C.; Navarro Cáceres, P.; Pérez-Lloret, P.; Marín García, M.d.P. A Morphological and Morphometric Dental Analysis as a Forensic Tool to Identify the Iberian Wolf (*Canis Lupus Signatus*). *Animals* **2020**, *10*, 975. [\[CrossRef\]](#) [\[PubMed\]](#)
27. Sunquist, M.; Sunquist, F. *Wild Cats of the World*; Chicago University Press: Chicago, IL, USA, 2002.
28. Mazák, J.H. On the sexual dimorphism in the skull of the tiger (*Panthera tigris*). *Mam. Biol.* **2004**, *69*, 392–400. [\[CrossRef\]](#)
29. Farhadinia, M.S.; Kaboli, M.; Karami, M.; Farahmand, H. Patterns of sexual dimorphism in the Persian Leopard (*Panthera pardus saxicolor*) and implications for sex differentiation. *Zool. Middle East* **2014**, *60*, 195–207. [\[CrossRef\]](#)
30. Pocock, R.I. *Panthera pardus* (Linnaeus). The Leopard or Panther. The Fauna of British India, including Ceylon and Burma. *Mammalia* **1930**, *1*, 222–231.
31. Castelló, J.R. *Felids and Hyenas of the World, Princeton Field Guides*; Princeton University Press: Princeton, NJ, USA, 2020.
32. Kitchener, A.C.; Breitenmoser-Würsten, C.; Eizirik, E.; Gentry, A.; Werdelin, L.; Wilting, A.; Yamaguchi, N.; Abramov, A.V.; Christiansen, P.; Driscoll, C.; et al. A revised taxonomy of the Felidae. The final report of the Cat Classification Task Force of the IUCN/ SSC Cat Specialist Group. *Cat News Spec. Issue* **2017**, *11*, 80.
33. Meiri, S.; Dayan, T.; Simberloff, D. Variability and sexual size dimorphism in carnivores: Testing the niche variation hypothesis. *Ecology* **2005**, *86*, 1432–1440. [\[CrossRef\]](#)
34. Rohlf, F.K. Shape statistics: Procrustes superimpositions and tangent spaces. *J. Classif.* **1999**, *16*, 197–223. [\[CrossRef\]](#)
35. Slice, D.E. Landmark coordinates aligned by Procrustes analysis do not lie in Kendall's shape space. *Syst. Biol.* **2001**, *50*, 141–149. [\[CrossRef\]](#)
36. Bookstein, F.L. *Morphometric Tools for Landmark Data: Geometry and Biology*; Cambridge University Press: New York, NY, USA, 1991.
37. Dryden, I.L.; Mardia, K.V. *Statistical Shape Analysis*; John Wiley and Sons: New York, NY, USA, 1998.
38. Adams, D.C.; Rohlf, F.J.; Slice, D.E. A field comes of age: Geometric morphometrics in the 21st century. *Hystrix* **2013**, *24*, 7–14. [\[CrossRef\]](#)
39. Bookstein, F.L. Principal warps: Thin plate spline and the decomposition of deformations. *Trans. Pattern Anal. Mach. Intell.* **1989**, *11*, 567–585. [\[CrossRef\]](#)

40. Cohen, J. *Statistical Power Analysis for Behavioural Sciences*; Routledge: New York, NY, USA, 1988.
41. Schurimann, D.L. A comparison of the two one-sided test procedure and the power approach for assessing the equivalence of average biovariability. *J. Pharm. Biopharm.* **1987**, *15*, 657–680. [[CrossRef](#)] [[PubMed](#)]
42. Yuen, K.K.; Dixon, W.J. The approximate behaviour and performance of the two-sample trimmed t. *Biometrika* **1973**, *60*, 369–374. [[CrossRef](#)]
43. Yuen, K.K. The two-sample trimmed t for unequal population variances. *Biometrika* **1974**, *61*, 165–170. [[CrossRef](#)]
44. Benjamin, D.J.; Berger, J.O. Three recommendations for improving the use of *p*-values. *Am. Stat.* **2019**, *73* (Suppl. 1), 186–191. [[CrossRef](#)]
45. Colquhoun, D. The False Positive Risk: A proposal concerning what to do about *p*-values. *Am. Stat.* **2019**, *73* (Suppl. 1), 192–201. [[CrossRef](#)]
46. Arriaza, M.C.; Yravedra, J.; Domínguez-Rodrigo, M.; Maté-González, M.A.; García-Vargas, E.; Palomeque, J.F.; Aramendi, J.; González-Aguilera, D.; Baquedano, E. On applications of micro-photogrammetry and geometric morphometrics to studies of tooth mark morphology: The modern Olduvai Carnivore Site (Tanzania). *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **2017**, *488*, 103–112. [[CrossRef](#)]