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A biometric analysis of the pelvic acetabulum as an indicator of sex in bovids

Analyse biométrique de l'acetabulum pelvien en tant qu'indicateur du sexe chez les bovidés

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ABSTRACT

Despite its potential importance in the reconstruction of hunting strategies and subsistence patterns, determining sex in zooarchaeological assemblages is a task that has been often neglected because the assemblages consist mainly of fragmentary bones. Only a limited amount of research has been focused on sexing individuals at archaeological sites. Although dimorphic elements in skeletal anatomy (e.g., horns) are the most widely used indicators for sexing, other skeletal parts, such as the pelvic acetabulum provide valuable information to identify sex. The present work builds upon previous research and indicates the most useful indicators in the pelvic acetabulum to distinguish sex in bovids, with the goal of providing an analytical basis to expand interpretations of carcass acquisition strategies by humans.

RÉSUMÉ

En dépit de son importance potentielle dans la reconstitution des stratégies de chasse et des systèmes de subsistance, la détermination du sexe dans les assemblages zooarchéologiques a souvent été négligée, en raison de la nature fragmentaire des assemblages d'os. Seule une partie limitée de la recherche a été focalisée sur la détermination du sexe des individus sur les sites archéologiques. Bien que la présence d'éléments dimorphes dans l'anatomie du squelette (par exemple les cornes) ait été largement utilisée dans la détermination du sexe, certaines parties du squelette apportent des informations très valables en la matière. L'une des plus importantes est l'acetabulum pelvien. Le présent travail est construit à partir d'une recherche antérieure et met en évidence les indicateurs les plus utiles dans l'acetabulum pelvien pour la détermination du sexe chez les bovidés, dans le but de fournir une base analytique pour élargir l'interprétation des stratégies d'acquisition des carcasses par l'Homme.

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1. Introduction

Sex identification of animals accumulated in archaeofaunal assemblages is a potentially useful tool for the reconstruction of hunting strategies and subsistence of prehistoric human groups (Arceredillo et al., 2011; Davis et al., 2012; Greenfield, 2002; Munro et al., 2011; Weinstock, 2000). The difficulties of sexing fragmented archaeofaunal collections have often been stressed in zooarchaeological studies (e.g., Klein and Cruz-Uribe, 1984; Munro et al., 2011). The main reason for this is the state of fragmentation in which archaeologists find faunal remains, or the absence of diagnostic elements. Sexing is possible through particular traits or morphological features (e.g., antlers in cervids, horns in bovids, the presence or absence of canines in equids, the presence of a baculum in carnivores) or the pelvis shape (Davis, 1987; Greenfield, 2002; Klein and Cruz-Uribe, 1984; Munro et al., 2011; Ruscillo, 2003). In addition, sexing can also be approached through the biometrics of certain skeletal parts, such as metapodials.

Sexing archaeofaunal remains could play a major role in the reconstruction of subsistence patterns and hunting strategies by early hominins. Certain carnivores show particular preferences when preying on different taxa. The spotted hyena, for example, displays a preference for males in the case of wildebeests, with a sex ratio of 1.84:1 in the Seregeti (Kruuk, 1972); this is also documented when they prey on Thomson's gazelles (ratio = 3.1:1) (Kruuk, 1972). In contrast, spotted hyenas prefer females when they kill zebras (0.5:1 Seregeti; 0.4:1 Ngorongoro) (Kruuk, 1972), showing that they can be selective hunters.

Lions also prefer males when they kill wildebeest (2:1) in the Serengeti (Schaller, 1974). They show no sex preference when killing zebras and buffalos (1:1), except with older individuals, in which case males are hunted more frequently. In the case of Thomson's gazelle, lions prey on one sex or another depending on the season (Schaller, 1974).

Leopards especially prey on male Thomson's gazelles (73%), but they prefer females when they kill reedbucks in the Serengeti (Schaller, 1974). Cheetahs show no sex preference when they prey on Thomson's gazelle in the Serengeti, but, in contrast to lions, they prey more on females when they hunt older individuals (Schaller, 1974). Wild dogs also show preferences for male Thomson's gazelles (Schaller, 1974).

These few examples show that carnivores are selective hunters when it comes to the sex of the prey. They have preferences among species and frequently display preferences of one prey sex over the other depending on each species (Kruuk, 1972; Mills, 1990; Schaller, 1974). Potential scavenging hominins should display a selection of prey sex coincident with those of the carnivores that they scavenge from. Archaeological examples of sex selection or the lack thereof abound in the zooarchaeological literature. For example, Arceredillo et al. (2011) observed that Neanderthal groups killed more males than females of chamois at the site of Valdegoba (Burgos, Spain). In contrast, Weinstock (2000) concluded that because males and female reindeer were equally hunted at the site of Stellmoor (northern Germany), the groups at this site practiced non-selective hunting.

Sexing specific taxa have been carried out using biometric features (e.g., Arceredillo et al., 2011; D′Errico and Vanhaeren, 2002; Greenfield, 2002; Munro et al., 2011; Tchernov et al., 1990; Weinstock, 2000), statistical methods (e.g., Arceredillo et al., 2011), discrete traits (e.g., D′Errico and Vanhaeren, 2002; Munro et al., 2011; Prummel and Frisch, 1986; Ruscillo, 2003), or using DNA analysis (McGrory et al., 2012, Svensson et al., 2008). Munro et al. (2011) provided a list of traits to distinguish the sex for *Gazella gazella* (mountain gazelle) using traits such as the atlas, whose caudal wings are more robust in males than females; the body, being broader and higher in males than females; the glenoid cavity of the scapula, ovoid in females and round in males; and the pubic symphysis, where the pubic arch is V-shaped in males and U-shaped in females. D′Errico and Vanhaeren (2002) differentiated between red deer males and females through morphological and metrical variables taken from canines. Svensson et al. (2008) and McGrory et al. (2012) analyzed DNA from cattle metacarpals and mandibles, respectively, in order to separate sexes. Prummel and Frisch (1986) proposed how to differentiate male and female sheep through differential pelvic morphology. Greenfield (2002) used different measurements from the acetabulum to determine the sex of cervids and bovids, and some of these characters constitute the bulk of the present study.

The innominate is one of the best indicators of sex in mammals due to the effects of reproduction upon the skeletal structure (Greenfield, 2002). The medial faces of the iliac and the pubic areas have several diagnostic traits that are very useful to determine sex from complete or partially complete specimens (Greenfield, 2002). One of the most important diagnostic characters is the medial wall of the acetabulum, which is thinner and shorter in females and higher and more robust in males. As Greenfield (2002) noticed, this feature was addressed early in both German and English literature (Boessneck et al., 1964; Grigson, 1982; Lemppenau, 1964; Prummel and Frish, 1986; Von Leithner, 1927). However, other acetabular features have been neglected in the literature (Greenfield, 2002).

The aim of the present study is to test the characters used by Greenfield (2002) to determine sex on a wider array of bovid taxa. It will be shown that the sex of individual carcasses can be confidently obtained through several types of measurements of the pelvic acetabulum.

2. Sample and method

The specimens included in the present study belong to adult African bovids. Initially, the goal was to obtain the measurements of as many modern African bovids as possible. However, because of sample size (i.e., limited number of individuals per taxon) and also because portions of the bovid collections curated at museums are not properly sexed (see also Greenfield, 2002), we could only test Greenfield's (2002) diagnostic acetabular characters on a total of eight African bovid taxa. The sample was composed of 109 individuals, including a total of 172 acetabula. This number results from the presence of some incomplete innominates in the collection. Both sides of the pelvis were measured (when available) to account for potential asymmetry (see Lyman, 2006). All the acetabula were equally measured; that is, all variables as described below were taken.

The species included in this study were: *G. dorcas* (dorcas gazelle), *G. granti* (Grant's gazelle) among Antilopini; *Alcelaphus buselaphus* (hartebeest) among Alcelaphini; *Tragelaphus strepsiceros* (Kudu), *Taurotragus oryx* (eland), and *Tragelaphus scriptus* (bushbuck) among Tragelaphini; *Aepycerus melampus* (impala) among Aepycerotini; and *Kobus ellipsiprymnus* (waterbuck) among Reduncini (Table 1). All the individuals measured were adults.

Measurements were collected on specimens from the zoology collections of the Natural History Museum of London and the "Museum national d'histoire naturelle" of Paris. Measurements were taken with digital calipers.

For the present study, eight measurements were taken. Three of them were suggested by Greenfield (2002), two by Von den Driesch (1976) and the remaining three are proposed by the authors. They are described below (Fig. 1):

Table 1
List of taxa in which the analysis was conducted, showing the number of specimens and sex.
Tableau 1
Liste des taxons dans lesquels l'analyse a été effectuée, montrant le nombre de spécimens et le sexe.

Species	Total acetabulae	Sex
Aepycerus melampus	13	Male
Aepycerus melampus	16	Female
Alcelaphus buselaphus	10	Male
Alcelaphus buselaphus	8	Female
Gazella dorcas	13	Male
Gazella dorcas	8	Female
Gazella granti	13	Male
Gazella granti	6	Female
Kobus ellipsiprymnus	8	Male
Kobus ellipsiprymnus	8	Female
Taurotragus oryx	8	Male
Taurotragus oryx	6	Female
Tragelaphus scriptus	22	Male
Tragelaphus scriptus	20	Female
Tragelaphus strepsiceros	6	Male
Tragelaphus strepsiceros	6	Female
Total	171	

H1: the height of the medial wall of the acetabulum (Greenfield, 2002). The arms of the caliper must be placed above and below the medial wall in the centre of the acetabulum, pressing to ensure that the arms do not move and thus avoiding mistakes when the measurement is taken. One arm of the caliper is resting internally on the acetabular surface (Fig. 1) (see further examples in Greenfield, 2002).

H2: the height of the acetabular medial wall (Greenfield, 2002). This measurement is taken by placing the arms of the caliper on both edges of the wall, in the midsection of the wall. In this case, the upper arm of the caliper does not rest inside the articular surface of the acetabulum (see Fig. 1). H2 is one of the most objective and reliable measurements because the arms of the caliper stand on both edges of the wall, avoiding deviation.

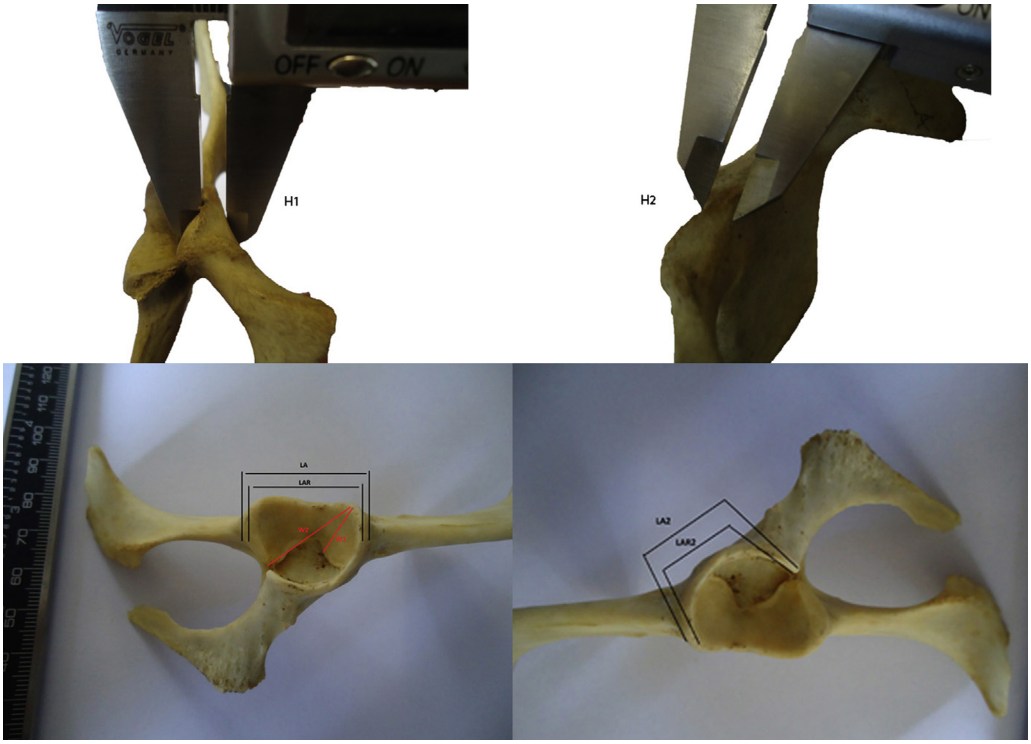

Fig. 1. (Color online.) Examples of how to take the measurements described in the present work. See description Methods section of text.
Fig. 1. (Couleur en ligne.) Exemples de la manière dont sont prises les mesures dans la présente étude. Voir le paragraphe « Description des méthodes » dans le texte.

LA: the length of the acetabulum including the lip (Greenfield, 2002; Von den Driesch, 1976). It is taken from the lateral face of the acetabulum. According to Von den Driesch (1976), this measurement is not recommended for species that have no lip in the acetabulum.
LAR: the internal length of the acetabulum from the lateral side (Greenfield, 2002; Von den Driesch, 1976). Its use is recommended for species that have no lip in the acetablum (Von den Driesch, 1976).
W1 (Greenfield, 2002) and W2 (the authors): the width of the acetabulum. It is taken from the edge of the acetabular rim to the end of the incisura acetabular. For open acetabula, both measurements are taken. However, for closed acetatulae only W2 is taken. In this case, it is not possible to take W1 because one of the arms of the caliper cannot be placed.

Some additional variables have been added to the study:

LA2: external length of the acetabulum. It is taken from the medial side, including the lip.
LAR2: internal length of the acetabulum. It is also taken from the medial side.
H1_LA, H1_LA2, H1_LAR, H1_LAR2: These are ratios between different length variables as described above and the thickness of the medial wall of the acetabulum, also as described above.
H2_LA, H2_LA2, H2_LAR, H2_LAR2: These are ratios between different length variables as described above and the external height of the acetabular wall.

2.1. Statistical method

A principal component analysis (PCA) was carried out using the "FactoMineR" library of R (www.r-project.org). Variables were scaled prior to analysis. Given the high portion of sample variance explained, a two-component solution was selected. The PCA aimed at differentiating the sex of each case within a Euclidean space. A comparative analysis of the scores provided by the eight taxa was also undertaken in order to conclude whether sex differentiation was effectively made regardless of taxon.

Once the variables that more effectively determined sex were identified, a logistic regression (LR) was carried out to determine the ratio of these variables that discriminated between male and female acetabular morphology. This was done by using a general linear model (GLM) using a binomial family. The procedure was carried out by a stepwise removal of variables according to their significance in the final solution and the percentage of sample variance explained (adjusted R2).

3. Results

A PCA yielded a two-component solution, in which > 97% of the sample variance was explained. The first component explained most of the inertia (85.25%), compared to the second component (11.95%). The alpha bags (i.e., confidence ellipses) showed no overlap in the 95% confidence intervals of the male and female subsamples (Fig. 2). When the sample was displayed according to taxon, a complete overlap was observed, which documents that the sex separation provided by the variables used is not dependent on species or body size. As can be seen in Fig. 2, the confidence ellipses of all taxa overlap, showing that although a slight allometry is identified in *Taurotragus oryx*, the rest of taxa overlap significantly. Thus, large animals such as *Tragelaphus strepsicerus* overlap with a large portion of the *Aepycerus melampus* sample. Furthermore, beyond the boundaries of the confidence intervals, individual data from the smaller *Tragelaphus scriptus* overlap with the whole range of the spread of the large-sized *Taurotragus oryx* data and display an even wider range on the first component. Therefore, variation in size is not reflected on the first component, with small and large taxa showing similar positions along its range. If anything, size seems to be more discriminant on the second component (which only explains 11.95% of the sample variance) and even here, the separation of taxa is minimal, with all taxa clustering around the axes of both components.

The ratio variables displayed a higher loading score than the traditional acetabular variables. This indicated a wider morphological variability in the shape and dimensions of acetabula, when using the complete taxonomic sample, and also indicates that the best approximation to differentiating sex is to use a proportion of the acetabular wall height and its length, which effectively overcomes this variability. H2_LA2 (0.9366) and H2_LA (0.9363) are the two variables that best determine the first component, with a correlation score > 0.9, followed by the other ratio variables. Loading scores for the second component are more evenly divided among all the variables, with H2 showing the highest score (0.4) and the other variables ranging from 0.34 to 0.37 (Table 2).

The PCA suggests that the highest score-yielding variable for the first component should be selected for a logistic regression (LR). This LR produced a solution in which H2_LA2 was again selected as the most useful variable to identify both sexes regardless of taxon (Fig. 3). The LR analysis showed that the probability of correctly identifying a female based on the acetabular height and length was higher than 80% when the ratio was < 0.2 and the same applies to identifying most of the males, when the H2_LAR2 ratio was > 0.3. Although most of the acetabulae whose ratio was comprised between 0.2 and 0.3 belonged to males, this portion of the ratio range was more ambiguous in sex identification.

4. Discussion

The present work has provided some verification of which measurements are best able to distinguish sex in bovid osteological assemblages when using the pelvic acetabulum.

Most of the sexing studies have focused on non-Palaeolithic contexts (e.g., Davis et al., 2012; McGrory et al., 2012; Munro et al., 2011; Prummel and Frisch, 1986; Svensson et al., 2008; Tchernov et al., 1990; Zeder, 2001). Only a few attempts to sexing carcasses have been applied to Palaeolithic assemblages. For example, Weinstock (2000) reconstructed sex profiles of reindeer

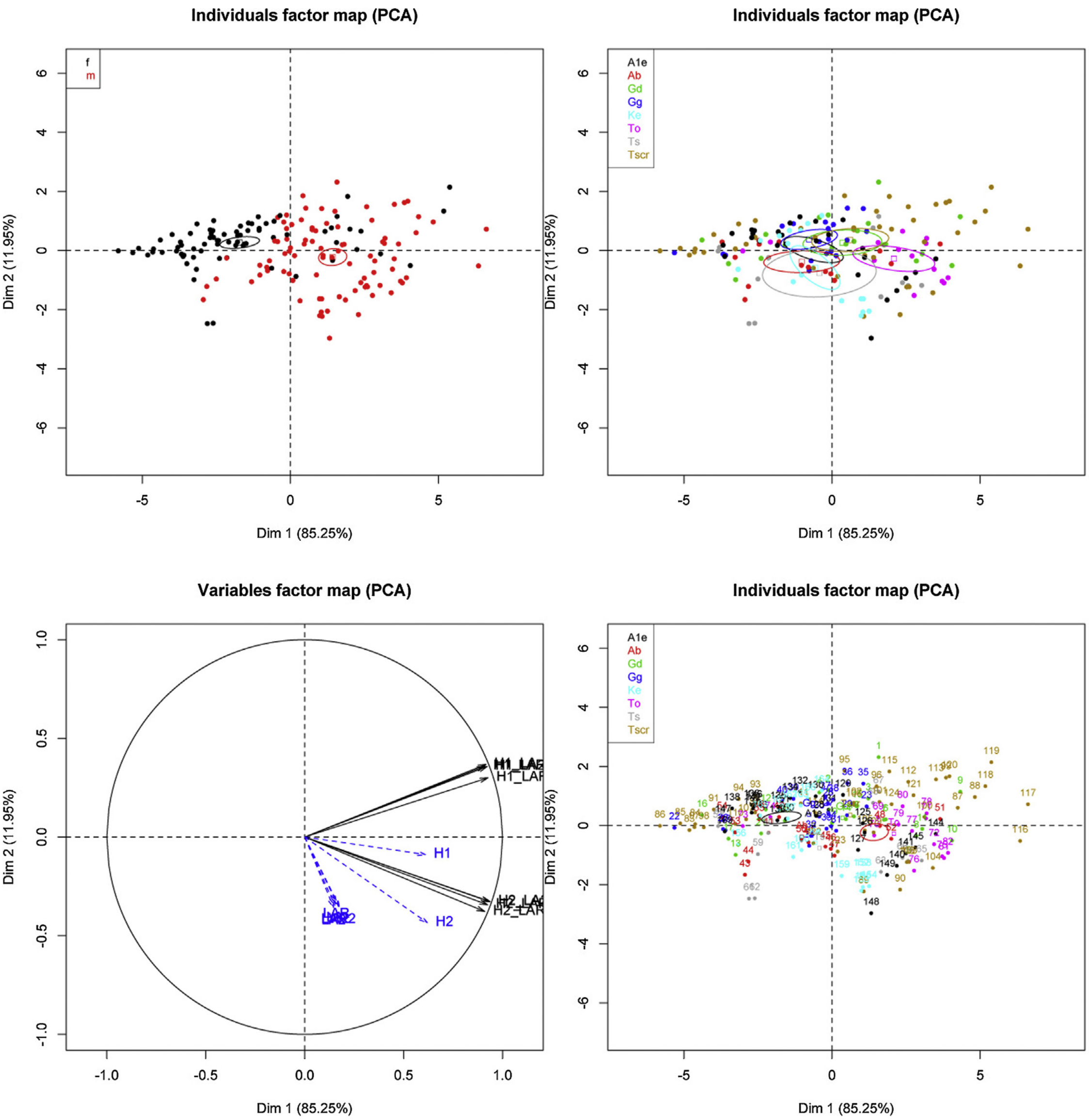

Fig. 2. (Color online.) Principal component analysis (PCA) of the 8-taxon bovid sample, showing clear separation of both sexes (upper left), with complete overlap when the sample is displayed according to taxon (upper right). The variables factor map (lower left) shows how most variables contribute to the first component. The individuals factor map (lower right) displays each acetabulum measured according to taxon and the alpha bags show that both sexes are completely separated. Key: f, female; m, male; A1e, *Aepycerus melampus*; Ab, *Alcelaphus buselaphus*; Gd, *Gazella dorcas;* Gg, *Gazella granti;* Ke, *Kobus ellipsiprymnus;* To, *Taurotragus oryx;* Tscr, *Tragelaphus scriptus;* Ts, *Tragelaphus strepsiceros.*

Fig. 2. (Couleur en ligne.) Analyse en composantes principales d'un échantillonnage de 8 taxons de bovidés, montrant une séparation nette entre les deux sexes (en haut à gauche), avec un complet recouvrement quand l'échantillonnage est présenté selon le taxon (en haut à droite). La carte de facteur des variables (en bas à gauche) montre combien la plupart des variables contribue à la première composante. La carte de facteur des individus (en bas à droite) présente chaque acetabulum mesuré selon le taxon et les sexes complètement séparés, d'après les ellipses de confiance. Signification : f, femelle ; m, mâle ; A1e, *Aepycerus melampus* ; Ab, *Alcelaphus buselaphus* ; Gd, *Gazella dorcas* ; Gg, *Gazella granti* ; Ke, *Kobus ellipsiprymnus* ; To, *Taurotragus oryx* ; Tscr, *Tragelaphus scriptus* ; Ts, *Tragelaphus strepsiceros*.

at the Late Glacial Site of Stellmoor (Northern Germany). Arceredillo et al. (2011) sexed *Rupicapra* carcasses at Valdegoba Cave (Burgos, Spain) with the aim of verifying if Neanderthals had sex preferences when they hunted chamois, showing that they killed more males than females. D'Errico and Vanhaeren (2002) elaborated a method for identifying canines from red deer to know the sex of perforated canines used as personal ornaments.

The present work has taken Greenfield's (2002) and Von den Driesch's (1976) studies, as a foundation. According to Greenfield (2002), H1 provides clear results and allows sexing animals successfully. The present study supports this statement, H1 being one of the measurements that is more useful to separate sex. However, Greenfield (2002) points out that H2 yields less satisfactory results than H1, and he considers it difficult to measure and less suitable to

Table 2
Loading scores of the correlation values and their significance of the PCA. See key to variables in the main text.
Tableau 2
Scores de charge des valeurs de corrélation et leur signification dans l'analyse en composantes principales. Se reporter aux variables dans le corps du texte.

$Dim.1	Correlation	*P* value	$Dim.2	Correlation	*P* value
H2_LA2	0.9366728	4.304780e−77	H1_LA	0.3684251	$9.643772e^{-07}$
H2_LA	0.9363104	6.789502e−77	H1_LAR2	0.3595818	$1.819268e^{-06}$
H1_LAR	0.9267806	4.523151e−72	H1_LA2	0.3571098	$2.165138e^{-06}$
H2_LAR2	0.9252839	2.255983e−71	H1_LAR	0.3002408	$8.074854e^{-05}$
H1_LA2	0.9220606	6.427515e−70	LAR	−0.3254904	$1.769614e^{-05}$
H1_LA	0.9170026	9.308281e−68	H2_LA2	−0.3260898	$1.704110e^{-05}$
H1_LAR2	0.9113372	1.703455e−65	H2_LA	−0.3276666	$1.542557e^{-05}$
H2_LAR	0.9104685	3.671126e−65	H2_LAR2	−0.3431643	$5.625825e^{-06}$
H2	0.6201422	4.007300e−19	LA	−0.3454030	$4.841061e^{-06}$
H1	0.6110027	1.812467e−18	W2	−0.3512011	$3.262953e^{-06}$
W2	0.1749704	2.372158e−02	LAR2	−0.3519940	$3.089710e^{-06}$
LAR2	0.1709824	2.715530e−02	LA2	−0.3574867	$2.108634e^{-06}$
LAR	0.1596268	3.934398e−02	H2_LAR	−0.3770805	$5.086222e^{-07}$
LA	0.1521548	4.965212e−02	H2	−0.4338692	$4.701933e^{-09}$

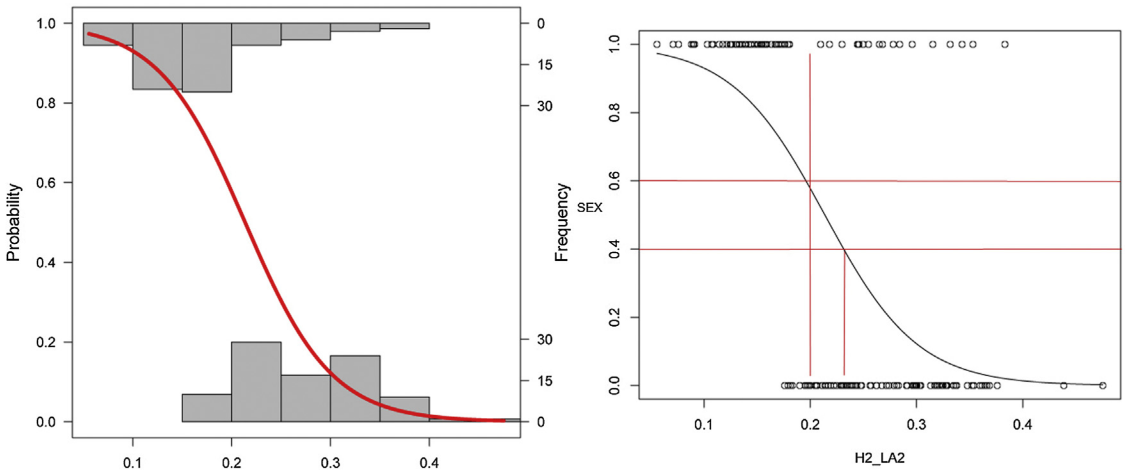

Fig. 3. (Color online.) Results of the logistic regression showing the differentiation threshold of males and females, using the H2_LA2 ratio. Males are coded as "0" and females as "1".
Fig. 3. (Couleur en ligne.) Résultats de la régression logistique montrant le seuil de différenciation mâles/femelles utilisant le rapport H2_LA2. Les mâles sont codés « 0 » et les femelles « 1 ».

separate sex. From our point of view, according to the results of the present work, H2 is not only slightly better than H1 to distinguish sex, although the difference between both measurements is small, but also H2 is the measurement that is taken better, thus more easily avoiding measuring errors. When H1 is measured with a calliper, there is the possibility that the arm does not rest on the centre of the acetabulum. H2 provides a more stable resting point to take measurements. Given that the calliper arms are adjusted to the wall, the possibility of displacement is lower.

In addition, we consider H2 a "visual measurement" because it is the only indicator that at first sight allows the analyst to determine sex owing to, as a rule, the medial wall of the acetabulum being lower in females and higher in males, as Greenfield (2002) noticed. Another advantage of this measurement is that it can be applied in fragmentary remains, since we only need the medial wall of the acetabulum to be preserved (Greenfield, 2002), whereas for the rest of the measurements, it is necessary to have the complete acetabulum.

LA and LAR measure the length of the acetabulum. They are measurements suggested by Von den Driesch (1976) and also used by Greenfield (2002). If they are applied in isolation, they are less effective than in combination with H1 and H2 (in the form of a ratio) to distinguish sex. Additionally, LA and LAR have certain disadvantages, as noted by Von den Driesch (1976), who recommends using LA for those species that have a lip in the acetabulum, and LAR for those species with no lip.

5. Conclusions

The importance of knowing the sex of the carcasses that archaeologists find in their assemblages can play an important role in their interpretation of sites, carcass acquisition strategies and subsistence patterns. The often fragmentary condition of most bones in the assemblages, especially those from the Palaeolithic period, or the absence of morphological characteristics such as horns, should not be an obstacle in the reconstruction of sex.

Several authors have considered the importance of pelvic features to identify sex (Boessneck et al., 1964; Davis, 1987; Greenfield, 2002; Grigson, 1982; Lemppenau, 1964 Munro et al., 2011; Prummel and Frisch, 1986; Von den Driesch, 1976; Von Leithner, 1927). Thus, the present study has taken Greenfield's study (2002) and his complete set of measurements in order to distinguish sex through certain measurements of the acetabulum and has created a standardized methodology that could be applied to bovids regardless of taxon. Considering the results of this work, we conclude that the medial acetabular wall is one of the most sensitive indicators of sex, as Greenfield (2002) noticed, and therefore some of the most useful measurements are those taken in this part of the pelvis.

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