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Auditory Exostoses in Pre-Hispanic Populations of the Lower Paraná Wetlands, Argentina

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ABSTRACT Auditory exostosis (AE) has been characterised from the medical and anthropological perspectives as an adaptive biological response to repeated immersion in cold water as well as exposure to cold environmental temperatures and wind chill. At the archaeological level, the highest prevalence has been found in societies living in coastal environments in areas located at 30–45° north or south latitude with a subsistence pattern based on fishing and mollusc gathering.

The region of the lower Paraná River wetlands in Argentina is an area dissected by multiple rivers, streams, and lakes, especially in the Paraná delta near Buenos Aires where these features create a landscape composed of many islands. A variety of archaeological analyses performed on faunal remains, stone tools, bone, and ceramic artefacts are consistent with the interpretation that towards the end of the late Holocene (2000–700 BP), this region was inhabited by hunter–gatherer populations with a subsistence pattern based mainly on fishing and hunting along with the gathering of molluscs. In this work, we present an analysis of 176 crania of individuals recovered from 21 archaeological sites in the region. Results indicate the presence of AE in 6.25% of the cases, with all of these corresponding to adult male individuals. This moderate prevalence coincides with the expected levels for populations where contact with water is frequent in regions located at 30–45° latitude. The absence of female individuals showing evidence of AE allows us to suggest a possible sex-based division of labour. We hope that this work can contribute to ongoing discussion of the economic and social aspects that characterised pre-Hispanic life in the study area, while also expanding the available information on AE at the worldwide level. Copyright © 2015 John Wiley & Sons, Ltd.

Key words: auditory exostoses; fishing activities; hunter–gatherer societies; sexual division of labour

Introduction

Auditory exostoses (AE) are a type of abnormal bony growths located inside of the ear canal, on either the posterior or the inferior walls of the lateral aspect of the tympanic portion of the temporal bone, and projecting towards the inside of the acoustic meatus. Their aetiology has been widely discussed since the end of the 19th century, with their origin generally being attributed to environmental/behavioural factors or genetic factors (Berry & Berry, 1967; Kennedy, 1986). Several experiments as well as clinical and archaeological observations tend to support the first cause rather than the second. Examples of such case studies include archaeological research on past populations of coastal environments (Standen *et al.*, 1997; Velazco Vázquez *et al.*, 2001) with economies based primarily on fishing and/or mollusc gathering (Frayer, 1988; Quevedo, 2000), and modern clinical cases of individuals who practice water sports such as surfing or diving (DiBartolomeo, 1979; Deleyiannis *et al.*, 1996). In all these cases, exposure of the auditory canal to cold water temperatures combined with a high frequency of such activities would have provoked irritation or infections of the external auditory canal, leading to the development of AE. In addition, studies of past and present populations have demonstrated that the manifestation of AE is only present in adult individuals, with a complete absence in individuals under the age of 15 years (Kennedy, 1986; Okumura *et al.*, 2007). In sum, all these examples have led to the general rejection of the genetic hypothesis.

In the 1980s, Kennedy (1986) carried out a cross-cultural study to evaluate the prevalence of AE in

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populations around the world located at a variety of latitudes and observed that the highest frequencies occurred from 30° to 45° north or south latitude, in comparison with those located between 0° and 30° or above 45° latitude. This study resulted in what is known as the *thermal aquatic hypothesis*, which proposes that the cause of the observed higher frequencies of AE in such latitudes is the practice of aquatic activities in water temperatures between 15 and 19 °C. The impact on the auditory canal caused by these water temperature had been established years before the observations made by Kennedy, because experiments with human subjects and pigs (Kennedy, 1986) observed that more erythema or hyperemia was caused in the auditory canal by application of small doses of cold water (15 °C) compared with application of water at higher temperatures (19 °C). In the case of the pigs, physiological changes were conducive to the stimulation of osteoblastic activity triggering the development of AE. In addition, recent studies have also noted that the process of ossification is not only caused by immersion in cold water, but that the environmental temperature and wind chill have similar effects on bone, and that the possibilities of manifestation are more or less proportional to the frequency of exposure to such environmental conditions (Okumura *et al.*, 2007).

The time required for the occurrence of AE varies between 5 and 10 years of exposure to cold water and/or cold environmental conditions (Chaplin & Stewart, 1998; Kroon *et al.*, 2002). In other words, the degree of bone occlusion in the auditory canal has a correlation with the frequency of exposure, the surface water temperature or environmental temperature, and latitude. However, it has been pointed out that the presence of AE could be due to chronic infections or inflammations in the auditory canal (Hutchinson *et al.*, 1997; Godde, 2010), although these aetiologies are associated with samples that show a low prevalence of AE (1% to 3%) (Kennedy, 1986; Godde, 2010).

One further aspect to be considered is the difference between AE and auditory osteomata, which can differ both macroscopically and microscopically. In the case of AE, bone growth is located on the anterior, inferior, and posterior surfaces of the tympanic portion of the temporal bone, projecting into the interior of the auditory canal in a bilateral and symmetrical manner. In contrast, auditory osteomata are benign tumours located at the tympanomastoid and tympanosquamosal sutures and are unilateral and asymmetrical. At a microscopic level, AE are composed of subperiosteal lamellae, numerous osteocytes, and no marrow spaces with a broad base, while osteomata consist of a normal cortex and cancellous interior filled with fibrous tissue, with a small or pedunculated base. Clinically, and in contrast to AE, osteomata are not associated with aquatic activities and are thought to be genetic in origin (Graham, 1979). Taken as a whole, these characteristics suggest that osteomata and AE differ in both their structures and aetiologies.

In Argentina, cases of AE have only been studied in two pre-Hispanic populations that lived near the southernmost permanently inhabited region of the world, in the province of Tierra del Fuego (Ponce *et al.*, 2008). One of the populations studied had a terrestrial hunter–gatherer economy and a prevalence of AE of 1.9% (one out of 53 crania). The other population was adapted to the use of marine resources, and 9.1% (five out of 55 crania) of the individuals studied showed AE. These results led the authors to argue in favour of the *thermal aquatic hypothesis*, and they believed that this higher prevalence resulted from the practice of aquatic activities in a cold environment with very cold water temperatures but with a low frequency of exposure because of the risk of hypothermia.

The study area for the present work is located in northeast Argentina, in the region of the lower Paraná River wetlands. Although the presence of AE was detected at the beginning of the 20th century (Torres, 1911), the broader occurrence of the phenomenon has never been analysed for the region in greater depth. The objective of the study presented here was therefore to analyse the presence of AE in a sample of 176 crania now curated in a variety of museum collections in Argentina and which were recovered from 21 archaeological sites in the lower Paraná wetlands (LPW), chronologically positioned at the end of the late Holocene (2000–700 BP). Later, we will evaluate the hypothesis that the occurrence of AE is associated with aquatic activities. In this sense, we will discuss the results of this study in terms of the overall prevalence of AE and its sex-based and age-based distribution in relation to the subsistence activities of the hunter–gatherer populations that inhabited the region at that time. In this way, we hope to contribute to discussions of the economic and social aspects that characterised the study area as well as to expand the available information on AE at a worldwide level.

Environmental and archaeological context

The LPW are located within the geographical region of northeastern Argentina, specifically in the south of the

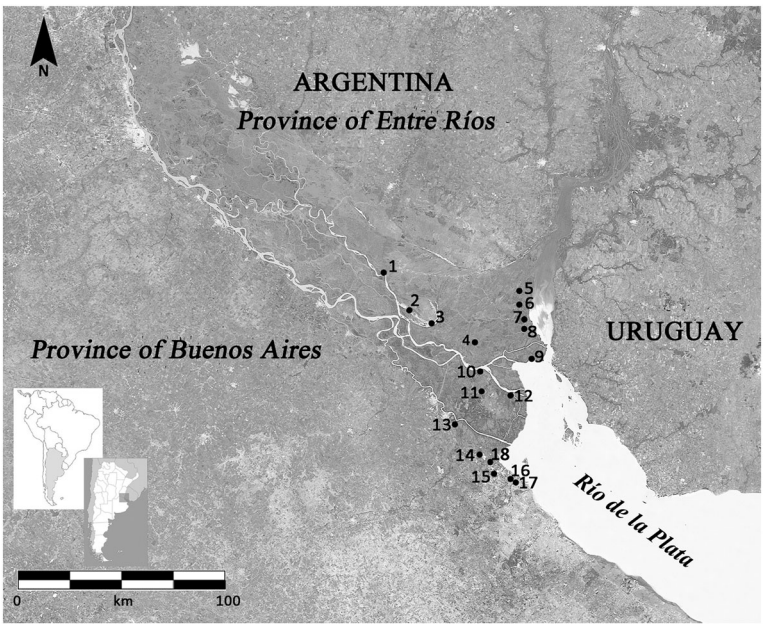

Figure 1. Location of the lower Paraná wetlands with the archaeological sites mentioned in the text. The map is adapted to the geological evolution of the area at 200 years BP (Atlas Ambiental de Buecnos Aires, 2007). (1) Paraná Ibicuy 1/La Argentina; (2) Mazaruca; (3) Escuela 31; (4) Túmulo 2 del Brazo Largo; (5) Las Ánimas; (6) Cerro Lutz; (7) Paranacito; (8) Túmulo 1 del Brazo Largo; (9) Brazo Gutiérrez; (10) Túmulo 2 del Paraná Guazú; (11) Arroyo Los Tigres and Arroyo Marieta; (12) Túmulo 1 del Paraná Guazú/El Cerrillo; (13) Túmulo de Campana Site 1; (14) El Cazador site 3; (15) Garín; (16) Arroyo Sarandí; (17) La Bellaca Site 2; (18) San Fernando. The location of the archaeological site named Arroyo La Garza is unknown.

province of Entre Ríos and northeast of the province of Buenos Aires (33.7°–34.4° S and 58.3°–59.6° W) (Figure 1). It is part of the southern end of the Paraná–Plata basin and as such has a landscape shaped by the presence of multiple rivers and channels flowing into the estuary of the Río de la Plata (Loponte, 2008). At the environmental level, the LPW has a subtropical climate, which is due to the influence of the Paraná and Uruguay rivers that extend the warmer climates found in more northerly zones (Paraguay and southern Brazil) into the study area. The average annual temperature is 16–16.5 °C, with a very significant range of annual maximum (36–38 °C) and minimum (0–5 °C) temperatures (Silva Busso *et al.*, 2004). The average surface water temperature during the South American winter (from July to September) is 14–15 °C, while during the summer (from December to March), it is 23–24 °C[1] (Atlas Ambiental de Buenos Aires, 2007; Instituto Nacional de Tecnología Industrial (INTI), 2010) (Figure 2).

Archaeological research in the LPW began towards the end of the 19th century and early 20th century, with a great emphasis on description of the materials obtained and the production of various types of chronological sequences (Zeballos & Pico, 1878; Outes, 1911; Torres, 1911). More recent studies have focused on the systematic analysis of archaeological collections using various lines of evidence and have established the existence, since 2400 BP with continuity until the arrival of the European explorers, of hunter–gatherer societies with economies where fishing represented a fundamental economic activity (Loponte, 2008; Musali, 2010) (Figure 3). The types of fishing-related artefacts recovered include detachable harpoon heads (Buc, 2007), which were being used in the region since at least 2300 BP (Loponte *et al.*, 2012). Also, based on the composition of archaeological fishbone assemblages, the use of nets and the bow and arrow can also be inferred (Loponte, 2008; Musali, 2010; Silvestre *et al.*, 2013). For the purposes of this study, it is important to point out the relevance of ethnographic data from the Chaco-Santiagueña region[2], which although located further to the north is part of the same ichthyogeographic region and is affected by the same pulsatile fluvial system. The human groups in this region show similar economic characteristics to those in the LPW (Loponte, 2008; Musali, 2010), and groups of individuals would practice fishing at depth during the cold weather months (June and July), submerging themselves in the cold water along with their fishing nets (Arenas, 2003).

[1]Surface water temperature data from the years 2007–2010.

[2]There is no relevant ethnohistorical information from the LPW area.

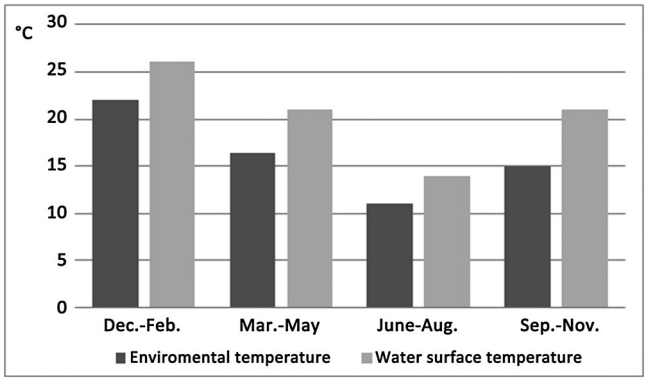

Figure 2. Annual distribution of environmental temperatures and surface water temperatures in the study area.

Materials and methods

The sample analysed for the present study consisted of crania from 176 individuals recovered from 21 archaeological sites (Table 1, Figure 1). Based on the geomorphological events that shaped the landscape as well as through the results of radiocarbon dating, the analysed sample can be located chronologically within the final phase of the late Holocene.

A high percentage (87.50%) of the analysed individuals are now curated in museum collections developed at the beginning of the 20th century, while the rest (12.50%) were retrieved in excavations carried out in recent years. This situation influenced the methods adopted for age estimation and sex determination for the sample, because in many cases, the cranial and postcranial skeletal elements of the individuals in museum collections were separated on their arrival at a museum or even just after excavation in the field (Lehmann-Nitsche, 1910). These former practices now make it impossible to relate these anatomical parts and therefore prevent analysis of the complete skeleton. Because of this, in the majority of cases (87.50%), sex determination could be carried out using only the skull following Buikstra & Ubelaker (1994) and by use of a discriminant function for the mastoid process generated specifically for the study area (Mazza, 2013). Age estimation for adult individuals was carried using the cranial suture obliteration approach (Meindl & Lovejoy, 1985) and using dental development for sub-adult individuals (Moorrees *et al.*, 1963; Ubelaker, 1989). In cases where the postcranial skeletal remains were present (12.42% of the cases), the os coxae were also used for sex determination (Phenice, 1969; Buikstra & Ubelaker, 1994), and age estimation also relied on the metamorphosis of the auricular surface of the ilium (Lovejoy *et al.*, 1985) and the pubic symphyseal surface (Brooks & Suchey, 1990). The sample was divided into males ($n = 96$), females ($n = 36$), probable males ($n = 27$), probable females ($n = 14$), and indeterminate ($n = 3$) (Table 2). The associations between the presence of AE and sex on the one hand and age on the other were evaluated by the chi-square

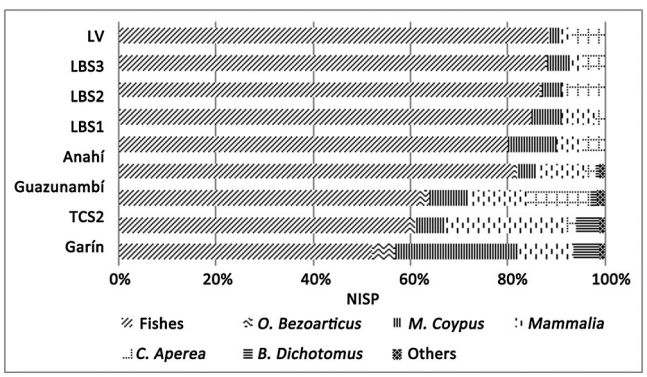

Figure 3. NISP faunal percentages from different archaeological sites in the region. LV, Vizcacheras; LBS1, La Bellaca Site 1; LBS2, La Bellaca Site 2; LBS3, La Bellaca Site 3; TCS2, Túmulo de Campana Site 2 (Loponte, 2008: 316).

Table 1. Archaeological sites showing the number of individuals analysed, radiocarbon dates, and institutional location

Sites	*n*	Location[a]	Years ^{14}C BP	Source[b]
Arroyo La Garza	1	MLP	<2000	(1)[c]
Arroyo Los Tigres	1	MLP	<2000	(1)[c]
Arroyo Marieta	4	MLP	<2000	(1)[c]
Arroyo Sarandí	6	MLP	1290 ± 40	(2–3)
Garín	1	INAPL	1360 ± 70	(3)
La Bellaca Site 2	1	INAPL	680 ± 80	(3)
Túmulo del Brazo Gutiérrez	28	MLP	742 ± 41	(4–5)
Túmulo 1 del Paraná Guazú/El Cerrillo	19	MLP	576 ± 42	(2; 4; 6)
Túmulo 2 del Paraná Guazú	29	MLP	846 ± 41	(4–5)
Túmulo 1 del Brazo Largo	9	MLP	656 ± 42	(4; 6)
Túmulo 2 del Brazo Largo	30	MLP	<2000 976 ± 42	(7)[c]
Cerro Lutz	14	INAPL	796 ± 42 730 ± 70	(8–10)
Escuela 31	1	INAPL	1897 ± 47	(9)
Las Ánimas	2	INAPL	1121 ± 31	(9)
El Cazador Site 3	3	INAPL	1110 ± 70	(11)
Mazaruca	3	MLP	<2000	(12)
Paraná Ibicuy 1/La Argentina	2	MLP	979 ± 44	(13)
Paranacito	9	MET	<2000	(14)[c]
San Fernando	11	MLP	<2000	(15)[c]
Túmulos Cercanos a Túmulo 1 del Paraná Guazú	1	MLP	<2000	(16)[c]
Túmulo de Campana Site 1	1	MLP	1754 ± 49	(17)
Total	176			

[a]MLP, Museo Nacional de Ciencias Naturales y Museo, La Plata; INAPL, Instituto Nacional de Antropología y Pensamiento Latinoamericano; MET, Museo Etnográfico de la Facultad de Filosofía y Letras, Universidad de Buenos Aires.
[b](1) Castro (1927); (2) Lothrop (1932); (3) Loponte (2008); (4) Torres (1911); (5) Bernal (2008); (6) Bonomo *et al.* (2011); (7) Gaggero (1924); (8) Acosta & Loponte (2006); (9) Loponte & Acosta (2007); (10) Mazza (2010); (11) Loponte y Acosta (2011); (12) Lista (1878), Torres (1903); (13) Caggiano *et al.* (1978); (14) Gatto (1938); (15) Torres & Gaggero (1929); (16) Olivera (1926); (17) Zeballos & Pico (1878).
[c]For this group of archaeological sites, there are no publications related to the human remains recovered, and the only information available is the names of the researchers who deposited the collections at the national museums and the associated dates (Del Papa M, personal communication, 2012).

test, using a significance cut-off value of $p < 0.05$. The statistical analyses were carried out with PAST v. 2.10 (Hammer *et al.*, 2001).

The age profile of the study sample consisted primarily of adult individuals within an age range of 35–50 years ($n = 96$), followed by individuals above 50 years ($n = 36$), and with a low presence of individuals 20–35 years of age ($n = 8$) or sub-adult (<20 years; $n = 7$). There are also 29 individuals that could only be placed in the category of 'indeterminate adult' (Table 2), because of the poor state of preservation of certain anatomical elements as well as the reassembly techniques used in the early 20th century, which broke or obscured the cranial sutures and other anatomical features. These factors prevented observation of the degree of cranial suture obliteration as well as the degree of degeneration of the auricular surface of the ilium or the pubic symphyseal surface for age estimation, or observation of other features for sex determination. Also, the low presence of sub-adult individuals (below 20 years of age) may be due to the excavation and analysis techniques employed during the late 19th and early 20th centuries, which may have led to their destruction or their confusion with faunal remains, as well as to academic interests of the time that privileged the recovery of adult remains for purposes of racial comparisons (Farro, 2011).

The identification of AE and its differentiation from osteomata were performed macroscopically based on observation of a discrete formation of new bone occurring within the auditory canal and by considering bilateral symmetry (presence in both auditory canals of the same cranium) (Graham, 1979).

Finally, the degree of obstruction of the auditory canal was recorded according to the following scale: low (<1/3), moderate (1/3 to 2/3), or high (>2/3) (Standen *et al.*, 1997).

Results

Auditory exostoses were observed in 11 individuals (6.25% Table 3), all of these identified as male or probable male. The results of the chi-square test showed statistically significant differences between the

Table 2. Sex and age distribution of the analysed sample

		Sex					Age (years)						
Sites	*n*	M	PM	F	PF	I	0–3	3–12	12–20	20–35	35–50	+50	IA
Arroyo La Garza	1	–	–	1	–	–	–	–	1	–	–	–	–
Arroyo Los Tigres	1	1	–	–	–	–	–	–	–	1	–	–	–
Arroyo Marieta	4	4	–	–	–	–	–	–	–	–	3	–	1
Arroyo Sarandí	6	1	3	1	1	–	–	–	–	1	1	–	4
Garín	1	1	–	–	–	–	–	–	–	–	1	–	–
La Bellaca Site 2	1	–	1	–	–	–	–	–	–	–	–	–	1
Túmulo del Brazo Gutiérrez	28	13	4	9	1	1	–	–	–	–	21	6	1
Túmulo 1 del Paraná Guazú/El Cerrillo	19	9	4	3	3	–	–	–	1	–	9	3	6
Túmulo 2 del Paraná Guazú	29	15	2	6	5	1	–	–	–	2	12	7	8
Túmulo 1 del Brazo Largo	9	6	1	2	–	–	–	–	–	–	5	3	1
Túmulo 2 del Brazo Largo	30	23	2	3	2	–	–	–	2	2	15	10	1
Cerro Lutz	14	8	2	3	1	–	–	–	–	2	9	–	3
Escuela 31	1	–	–	1	–	–	–	–	–	–	1	–	–
Las Ánimas	2	–	1	–	–	1	–	1	–	–	–	–	1
El Cazador Site 3	3	2	1	–	–	–	–	–	–	–	1	2	–
Mazaruca	3	1	–	1	1	–	–	–	–	–	2	–	1
Paraná Ibicuy 1/La Argentina	2	2	–	–	–	–	–	–	–	–	–	2	–
Paranacito	9	5	2	2	–	–	–	–	1	–	7	1	–
San Fernando	11	5	4	2	–	–	1	–	–	–	9	1	–
Túmulos Cercanos a Túmulo 1 del Paraná Guazú	1	–	–	1	–	–	–	–	–	–	–	1	–
Túmulo de Campana Site 1	1	–	–	1	–	–	–	–	–	–	–	–	1
Total	176	96	27	36	14	3	1	1	5	8	96	36	29

M, male; PM, probable male; F, female; PF, probable female; I, indeterminate; IA, indeterminate adult.

prevalence of the condition in males and females in the sample ($X^2 = 4.32$; $df = 1$; $p < 0.05$). In terms of the classification system proposed by Kennedy (1986) into low (<5%), moderate (6–20%), and high prevalence (>21%), the overall sample would fall into the category of moderate. With regard to the age distribution, 54.55% ($n = 6$) of the 11 individuals affected are above the age of 50 years, while the remaining five individuals are divided between 35–50 years (36.36%, $n = 4$) and 20–35 years (9.09%, $n = 1$). Finally, there is a complete absence of affected individuals in the categories of less than 20 years of age. The differences among the ages are not statistically significant ($X^2 = 5.70$; $df = 5$; $p > 0.05$) (Figure 4).

In all 11 cases, the AE were located on the posterior wall of the tympanic portion of the external auditory canal and showed a presence on a bilateral basis. The degree of obstruction of the auditory canal was estimated as 'less than 1/3' in 72.73% of the cases ($n = 8$) and 'between 1/3 and 2/3' in the remaining 27.27% of the cases ($n = 3$), with no cases therefore showing obstruction of 'greater than 2/3' (Figure 5).

Discussion

The study carried out by Kennedy (1986) revealed a broad range in terms of the prevalence of AE as detected in regions at 30–45° north or south latitude, from a low of 2% occurrence to a high of 56%. In the LPW, which lies within this latitude range and which has environmental temperatures and surface water temperatures suitable for the development of AE, the prevalence of this bone-growth phenomenon was found in the present study to be 6.25%, a moderate value that lies within the expected range for this type of environment and for human societies with an economy based mainly on fishing.

These results may be related to the use of diving as one of the pre-Hispanic fishing techniques employed in the region, a practice that has already been inferred in previous works related to the local hunter–gatherer populations (Loponte, 2008; Musali, 2010). Indeed, some of the targeted fish species show demersal behaviours (such as *Pterodoras granulosus* and both local species belonging to the genus *Pseudoplatystoma*), and because

Table 3. Prevalence of auditory exostoses in the lower Paraná wetland with their sex-based distribution

		Individuals with auditory exostosis					
Archaeological sites	$n_{affected}/n_{total}$	M	PM	F	PF	I	Prevalence (%)
Arroyo La Garza	0/1	–	–	–	–	–	0
Arroyo Los Tigres	0/1	–	–	–	–	–	0
Arroyo Marieta	0/4	–	–	–	–	–	0
Arroyo Sarandí	0/6	–	–	–	–	–	0
Garín	0/1	–	–	–	–	–	0
La Bellaca Site 2	0/1	–	–	–	–	–	0
Túmulo del Brazo Gutiérrez	4/28	3	1	–	–	–	14.29
Túmulo 1 del Paraná Guazú/El Cerrillo	0/19	–	–	–	–	–	0
Túmulo 2 del Paraná Guazú	0/29	–	–	–	–	–	0
Túmulo 1 del Brazo Largo	1/9	1	–	–	–	–	11.11
Túmulo 2 del Brazo Largo	3/30	3	–	–	–	–	10
Cerro Lutz	2/14	2	–	–	–	–	14.29
Escuela 31	0/1	–	–	–	–	–	0
El Cazador Site 3	0/3	–	–	–	–	–	–
Mazaruca	0/3	–	–	–	–	–	0
Paraná Ibicuy 1/La Argentina	0/2	–	–	–	–	–	0
Paranacito	1/9	1	–	–	–	–	11.11
San Fernando	0/11	–	–	–	–	–	0
Túmulos Cercanos a Túmulo 1 del Paraná Guazú	0/1	–	–	–	–	–	0
Las Ánimas	0/2	–	–	–	–	–	0
Túmulo de Campana Site 1	0/1	–	–	–	–	–	0
Total	11/176	10	1	0	0	0	6.25

$n_{affected}$, number of individuals with auditory exostoses; n_{total}, total sample; M, male; PM, probable male; F, female; PF, probable female; I, indeterminate.

there are no local archaeological records of net weights or other types of devices designed to catch fish in deep water (Loponte, 2008; Musali, 2010), it seems likely that taxa such as these would have been captured through the use of hand-held nets while diving, as has been ethnographically recorded in other areas of the Paraná basin (Arenas, 2003; Musali, 2010). For example, in the nearby Chaco-Santiagueña region, the technique of 'diving' was used during the coldest months, which consisted of swimming in cold, deep water in search of fish while carrying nets. This technique was practiced by certain individuals considered to be skillful fishermen, who were always young adult men (Arenas, 2003). It has also been pointed out that such diving caused water to get inside the ears of the fisherman, which produced inflammation (Arenas, 2003:478). Hutchinson *et al.* (1997) pointed out that ear inflammation can be the result of a pH alteration in the external auditory canal caused by water influx and by the enhanced bacterial growth that results from elevated moisture or dermal hydration in the external auditory canal, and the formation of granulation tissue resulting from inflammation is known to provoke bone resorption. Therefore, it is highly likely that these activities, coupled with other aquatic activities in general, would have been the reason for the development of AE in certain individuals.

On the other hand, there is also some variability in the fishing techniques used by local human groups. In addition to the archaeologically recovered tool kit that includes harpoons with detachable bone heads (Buc, 2007), it is possible to infer the existence of fishing nets as well as the use of traps and poisons. These last two techniques, along with spearing and the use of the bow and arrow, do not require behaviours of submersion (Loponte, 2008; Musali, 2010). These different technological options for fishing could be a source of individual variability in the analysed population in terms of the generation of AE, depending on the degree of use of each tool kit over the lifetime of each individual. Furthermore, not all organisms react to submersion in the same way, and therefore, the presence of AE in modern populations reflects different degrees of impact on individuals under environmental pressures that are potential generators of this pathology (Chaplin & Stewart, 1998; Kroon *et al.*, 2002).

The presence of AE exclusively in the adult male population of the analysed sample is an indication of an environmental cause being related to this development. There are ethnographic data for a sector of the Paraná basin showing that each age group would participate in a specific set of fishing techniques. For example, among some populations of the Chaco region, groups of fishermen made up of children and

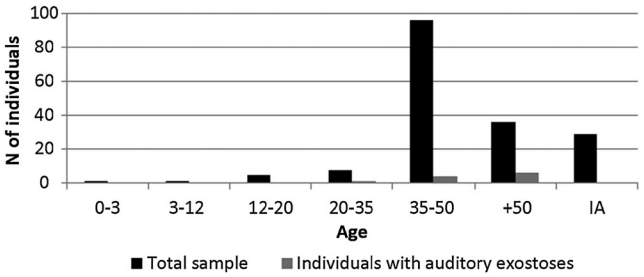

Figure 4. Age distribution of the total sample and for individuals with auditory exostoses. IA, indeterminate adults.

elderly men were arranged along the river with their nets, while another group would chase the fish into that area so they could be captured. Meanwhile, there were also young adult individuals who would dive in with their hand-held nets (Nordenskiöld, 1912; Scarpa, 2007). In addition to this age-based segmentation, there are also records reflecting a sexual division of labour, where fishing through the use of spears, nets, and the bow and arrow, and including the activity of submersion, was performed exclusively by men, while women would contribute to the effort using small baskets woven of vegetable fibres, small nets, and in some cases poisons (Nordenskiöld, 1912; Arenas, 2003). Taking into account this variability of activity, it would be expected that in the LPW, not all individuals would have used the same techniques to contribute to the obtainment of fish resources and that therefore not all individuals from the same population would develop the visible manifestations of AE.

Another aspect of the present study's results indicating that AE would have been a physiological response to prolonged exposure to cold water by immersion is the fact that this pathology is concentrated in adult individuals. In fact, in the analysed sample, AE is mostly present in adult individuals of 35–50 years of age and in the oldest age category of +50 years, being almost completely absent in young adults (20–35 years of age) and totally absent in sub-adults (<20 years of age). The prevalence of AE within these age categories ($n = 11$) is consistent with the hypothesis that considers the AE as an age-dependent pathology, with this argument based on the need for a minimum exposure time of the auditory canal to cold environmental conditions, ranging from 5 to 10 years, in order to allow AE to develop (Chaplin & Stewart, 1998; Kroon *et al.*, 2002).

Recent studies of AE have noted that the magnitude of the bone growth within the ear canal is highly correlated with the frequency with which the contributory water-based activity is practiced as well as the amount of time spent in the water (DiBartolomeo, 1979; Deleyiannis *et al.*, 1996; Chaplin & Stewart, 1998; Kroon *et al.*, 2002). Within the analysed sample, it was observed that the degree of ear canal blockage predominantly corresponds to the less severe degrees (72.73% of cases classified as 1/3 obstruction), with a few cases reflecting more moderate levels (27.27% between 1/3 and 2/3) and a total absence of individuals with relatively complete occlusion (>2/3). Because AE appears to be an age-related condition, we correlated the age of the individuals and the degree of obstruction using the Spearman correlation coefficient. Because the results show no statistical correlation ($r = 1$, $p > 0.05$), the pattern of ear canal blockage could indicate a decrease in the practice of aquatic activities and/or the amount of time individuals spent submerged in the water during the winter season, perhaps as a measure to prevent the physiological effects caused by swimming in waters with temperatures lower than 32 °C. Below this temperature, a chain of physiological effects leading to hypothermia can be experienced in the absence of adequate thermal insulation. In the Río de la Plata, with an average water temperature

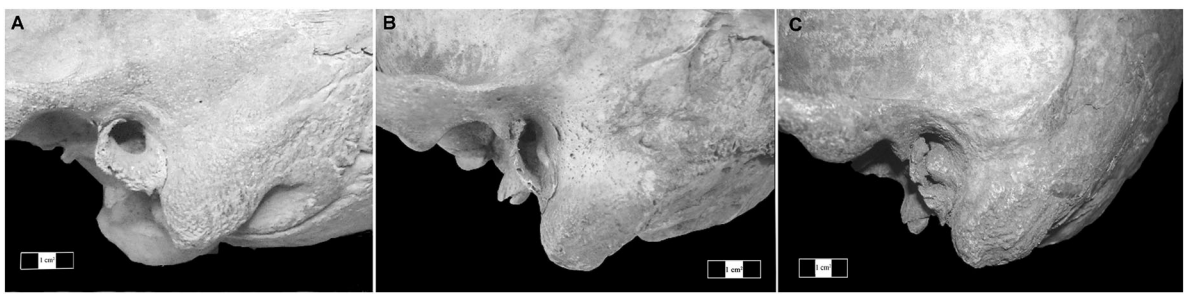

Figure 5. Degrees of auditory canal obstruction by the presence of auditory exostoses. (A) Absence; (B) <1/3; (C) 1/3–2/3 (sensu Standen *et al.*, 1997).

of 12 °C in the winter season, a fully clothed adult person can withstand the cold water for a little over an hour or for between 30 and 40 min if lacking any sort of outer protection (Silva, 2014). Métraux (1946:256) also noted that during cold weather, fishermen diving in Argentina's Pilcomayo River would hurry to warm themselves by a fire after securing their catch. In summary, considering factors such as these along with the observed patterns of auditory canal obstruction by AE in the present study, it is likely that the members of the hunter–gatherer societies studied in this work would have reduced their exposure to cold water during the winter as a preventive measure.

Finally, in addition to the aforementioned factors that would have influenced the presence of AE (variability in the methods used to obtain resources, sex-based and age-based division of labour, personal preferences, and time and frequency of exposure to cold water), we must take into account each individual's biological response. Discussions on the development of AE have argued in favour of the influence of factors including otitis, chronic infections, eczema, trauma, and any other pathological state that affects the normal homeostasis of the external auditory canal. Any of these alone or in combination could enhance the osteoblastic activity that results in AE (Hutchinson *et al.*, 1997). In contrast to the hypothesis that relates the aetiology of AE with otitis, Fuster *et al.* (1999) argued that the process is actually the reverse or, in other words, that it is the AE which leads to an otitis, because the presence of AE prevents the normal elimination of cerumen and scaly keratin, creating the conditions for the emergence of external otitis. Also, Kennedy (1986) argued that the aetiology related to otitis is relevant only in cases where the prevalence of AE does not exceed 3% (cf. Godde, 2010), a much lower proportion than that observed archaeologically for the LPW. In this regard, all the archaeological sites that were radiocarbon dated and with individuals presenting AE are within the range of 900–600 BP. This means that there is not a fragmentation of the prevalence among temporal periods that could decrease the observed results and lead us to argue in favour of a possible aetiology associated with otitis or other pathological states.

Conclusion

Although the presence of AE in the LPW was first described at the beginning of the 20th century, based on a single cranium recovered from an archaeological site studied by Torres (1911), this pathology has not previously been analysed in depth and in relation to a more extensive set of archaeological contexts. In the present work, we have recorded the presence of AE in 6.25% of a sample composed of 176 individuals of both sexes located chronologically within the final phase of the late Holocene. This degree of prevalence is within the expected range for hunter–gatherer societies with subsistence patterns based in part on fishing and mollusc gathering (Kennedy, 1986; Frayer, 1988; Quevedo, 2000; Ponce *et al.*, 2008).

Based on the arguments presented earlier, we could explain the prevalence of AE observed for the LPW as resulting from a combination of the following variables: the numbers of individuals practicing water-based activities, their individual physiological responses, the variability in the fishing techniques employed, the environmental conditions under which such activities were carried out, and the time of exposure to the relevant environmental conditions.

Finally, although the aspects of economic and social organisation mentioned as part of the present work have been ethnographically recorded for areas of northeastern Argentina, they had not previously been detected in the archaeological record for the LPW. The identification of AE as occurring primarily in middle-aged and older adult males represents a novel record regarding the importance of fishing in the hunter–gatherer societies of the LPW. It is also the first study to provide positive support for the hypothesis of a sexual division of labour among human groups in the area, which provides a further basis for discussing the aetiology of this condition. This in turn highlights the role that the bioarchaeological analysis of human remains can play in addressing topics that are almost inaccessible through the use of other types of archaeological materials, as well as the fact that existing collections of human remains found in national museums can serve as a valuable source of information.

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