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Experimental series and use-wear in bone tools

Natacha Buc*

INAPL-CONICET, 3 de Febrero 1370 (1426), C.A.B.A., Buenos Aires, Argentina

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ABSTRACT

This paper presents an experimental program and microscopic patterns identified in the analysis of five worked bone morpho-functional groups: harpoon heads, drilled points, bipoints, awls and smoothers.

Considering the common use hypotheses of each tool, the experimental program involved manufacture and use in impact, hafting, piercing and smoothing activities performed on animal carcasses, wood, skin, silica-rich plants and pottery. Not only a microscopic database of these hypothetical activities was obtained, but also it was tested the efficiency of tools to meet those mechanical requirements.

As other authors working on bone use-wear have previously asserted, each activity and material leaves particular use-wear patterns. Comparing my results with those of preexisting publications, I attempt to develop a general database useful to analyze archaeological bone tools.

1. Introduction: context of the study

This paper presents an experimental program and the resulting microscopic patterns in five morpho-functional groups of bone tools: harpoon heads, drilled points, bipoints, awls, and smoothers (Fig. 1).

This database was designed to analyze the archaeological bone tools sample from sites of the Low Paraná wetland, Argentina, dated in the Late Holocene, between 1100 and 700 years BP (Buc, 2010; some previous results were presented in Buc, 2005, 2007, 2008; Buc et al., 2010; Musali and Buc, in press). Environmental studies (*cf.* Loponte, 2008) show that actual conditions would have been stated at that moment, forming a landscape which is a mixture between floodplains and geoforms named “albardones” (rises in the ground of maximum 2 m.a.s.l. height) were sites are invariably located. Archaeological sites have homogeneous archaeological structures, being result of societies which based their subsistence on hunting cervids (*Blastocerus Dichotomus* –marsh deer– and *Ozotoceros bezoarticus* –pampa deer–) and rodents (*Myocastor coypus* and *Cavia aperea*), gathering vegetables and mollusks (mainly Diplodon *sp.*), and fishing (Silurids and Characiform species; Loponte et al., 2006). Pottery fragments are the most frequent items in the archaeological record; they are mostly plain, made on local clay and using pottery fragments as temper (Pérez, 2010). Given the absence of local quarries, lithic materials are scarce, mainly composed by natural flakes of quartzite or chalcedony (Buc and Silvestre, 2006; Loponte, 2008). In that context, bone technology played an important role in local strategies through the use of a wide variety of morpho-functional groups such as harpoons, drilled points, bipoints, awls and smoothers (see Fig. 1, Buc, 2010; Buc and Loponte, 2007).

The following section introduces the techniques and variables used in analysis of the experimental database (2). Considering the common use hypotheses of each morpho-functional group, the subsequent part of the article describes the experimental program itself (3). Finally, I summarize the use-wear obtained in each case (4) and discuss them with results of other authors (5).

2. Methodology

Despite the fact that use-wear analysis was first used by Semenov, 1964, is in the last decade that its application to bone tools has become more solid by an increase in international papers (*e.g.* Christidou, 2008; Gates St-Pierre, 2007; Legrand and Sidéra, 2007; Maigrot, 2005; Sidéra and Legrand, 2006; Gijn van, 2005, 2007) and PHD dissertations (Griffitts, 2006; Legrand, 2007; LeMoine, 1991; Maigrot, 2003; Sidéra, 1993). These works show the importance of developing experimental programs as well as the systematic observation and documentation of tools at different magnification for building reliable up-to-date databases.

Therefore, the first step in my analysis was to establish the main functional hypotheses of the abovementioned morpho-functional groups cited in local and global literature, according to the context of study. They are summarized in Table 1.

The manufacture and use of tools were analyzed under three different microscopes: a stereoscopic (Arcano XTL 3400), a metallographic or incidental (Zeiss Axiovert 100 A), and an

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* Tel.: +549 11 56 97 32 16.
E-mail address: natachabuc@gmail.com.

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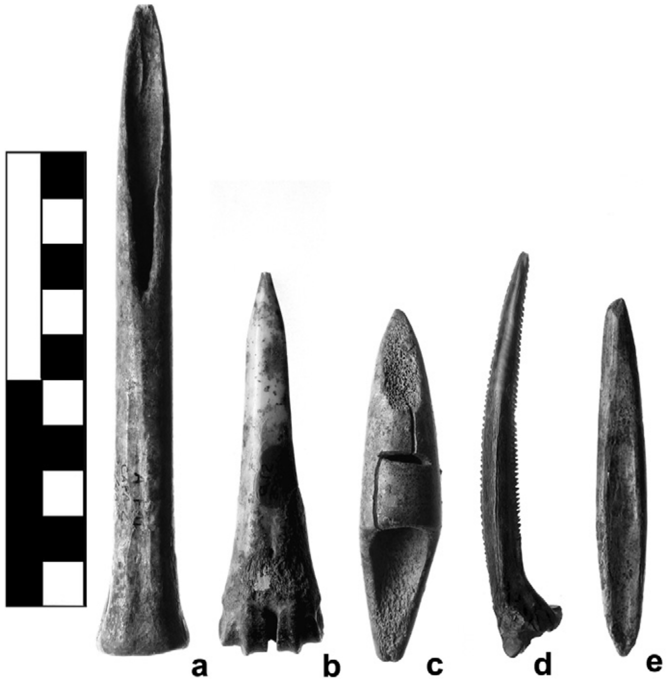

Fig. 1. Archaeological morpho-functional groups under analysis: a) drilled point, b) awl, c) harpoon, d) smoother, e) bipoint.

environmental scanning electronic microscope (ESEM). The metallographic microscope was used for the most part of the work; therefore, excluding specifications, analyze and microphotographs presented here were made with it.

For micro-wear description criteria of Legrand (2007; see also Legrand and Sidéra, 2007; LeMoine, 1991, and Sidéra and Legrand, 2006) were mainly followed, considering:

2.1. Volume alterations

According to physical and mechanical properties of bone material, wear modifies its original design (Sidéra, 1993; Maigrot, 2003; Legrand, 2007). In apical ends we can distinguish three types of alterations: rounding, flaking and flattening. Rounding is the result of repetitive wear (*e.g.* Semenov 1964; Sidéra, 1993; Maigrot, 2003; Legrand, 2007). Flaking is the micro-fracture on bone usually interpreted as consequence of percussion against a harder material (Maigrot, 2003), but, as Legrand stated, it can also be the result of extended use since bone surface becomes more brittle as long as it is used (Legrand, 2007: 68). Flattening would be the first stage in the wear process where bone fibers are retracted (Legrand, 2007).

Table 1
Morpho-functional groups and hypothetical functions.

MF-G	Functional Hypothesis	Reference
Harpoon	harpoon head	Nordenskjöld, 1929, Lothrop, 1932, Fontana, 1977[1881], Caggiano, 1977
Drilled Point	weapon head	Lothrop, 1932, Torres, 1911, Caggiano, 1977, Olsen, 1981
Awl	leather driller	Campana, 1989, LeMoine, 1991
	basketry	Campana, 1989, Olsen, 1979
Smoother	leather smoother	Liseau von Lettow-Vorbeck, 1998
	ceramic smoother	
	projectil point	Irving, 1992
Bipoints	projectil point	Lothrop, 1932, Tyzzer, 1936, Newcomer, 1974, Knecht, 1993, Guthrie, 1983
	bone rod	Lahren and Bonnichsen, 1974
	harpoon head	Fontana, 1997 [1881], Lyman, 1991, Pokines and Krupa, 1997
	fish gorges	Lyman, 1991, Rick et al., 2001, Smith, 1929 in Tyzzer (1936)
	multiple fishhook	Lyman, 1991

2.2. Micro-topography

Topography is the configuration of bone surface; so, its analysis involves descriptions of the high and low points' distribution (Legrand, 2007). When differences among high and low points are notorious, micro-topography is defined as heterogeneous (Fig. 2b). Conversely, if they are small, implying that both high and low points are affected by use, micro-topography will be homogeneous[1] (Fig. 2a).

2.3. Micro-relief

The analysis of micro-relief is a more detailed description of topography made at 200× (Legrand, 2007). If high points show the same height, micro-relief is defined as regular (Fig. 3a); but when there are important differences in their height, it will be named as irregular (Fig. 3b). Moreover, according to high points' morphology they could be rounded or flat, and, depending on their texture, rough or smooth (Fig. 3c–d).

2.4. Striations

Any lineal and deep trait seen in bone surface is considered a striation. They are classified according their distribution (seen at 50–100×) and morphology (seen at 200×; following Legrand, 2007).

Distribution (relative to tool's axis): transversal, longitudinal, random (Averbouh, 2000).

Arrangement (among striations): parallel, crossed, irregular.

Morphology

Width: narrow, wide (defined by the observer), variable (the same striation has different widths along its entire length).

Depth: deep, shallow (defined by the observer).

Length: long, short. Length is defined according they are shorter or larger than 1 μ (Legrand, 2007).

Form: straight, sinuous.

Internal features: coarse, smooth (*sensu* LeMoine, 1991); close V shaped, open V shaped.

3. Manufacture of experimental tools

Before beginning the manufacture process, bone surfaces were recorded in their natural state[2]. Considering the local archaeological record (1), we used three different bone raw materials: *B. dichotomus* or *Cervus elaphus* (red deer) antler, *Ovis aries* (sheep) long bones and fish spines from *Pterodoras granulosus* (catfish). Although *C. elaphus* and *O. aries* are not part of the raw materials used in the archaeological sample, they have morphological and metrical similarities with *B. dichotomus* and *O. bezoarticus* (respectively) which, nowadays, are species threatened with extinction.

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[1] Homogeneous and heterogeneous topography and regular and irregular micro-relief are terms that involve the alteration of surface points of different height. In that sense, they can be equivalent to invasive and non-invasive polish defined by LeMoine (1991: 58), respectively. However, I preferred the former pairs of terms because they do not involve definition of polish. As we discussed in a previous paper (Buc and Silvestre, 2006), archaeofaunal bones of Paraná wetland (without cultural modification) appear very bright under metallographic microscope, and, therefore, in this context polish cannot be treated as indicator of intentional use.

[2] In this stage, the only non-natural process that could have modified bones was boiling used to remove soft tissue in mammal long bones and fish spines.

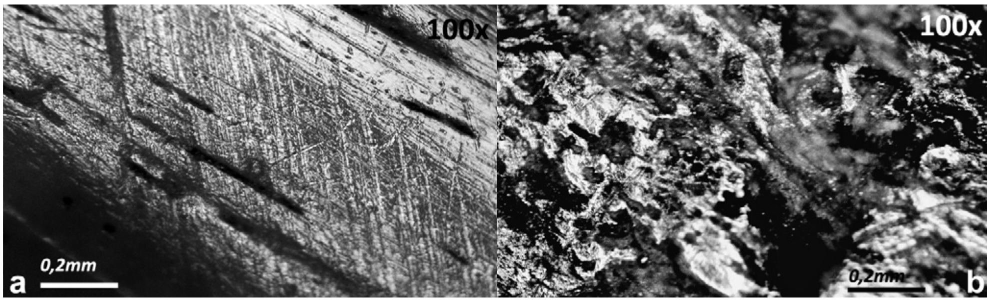

Fig. 2. Microtopography: a) homogeneous; b) heterogeneou.

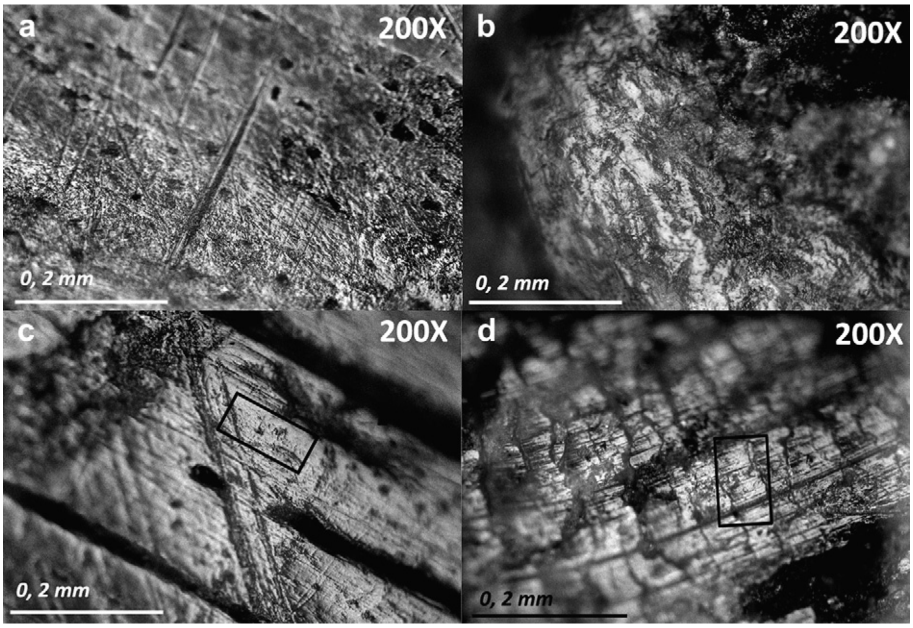

Fig. 3. Microrelief: a) regular; b) irregular; c) rounded and smooth high points; d) flat and rough high points.

Fig. 4 synthesizes results obtained after this first observation. Micro-topographies are heterogeneous and have natural grooves longitudinally oriented; a pattern clearly visible in fish spines (Fig. 4a). Antlers have a great quantity of marks made from cervid behaviors (Fig. 4c; see also Averbouh, 2000; Maigrot, 2003): these are short, wide or narrow, and randomly oriented striations. Even when they appear to be arranged in a regular pattern, they are found in various sectors of the beam.

We replicated the general form and dimension of the morpho-functional groups under analysis. Although identifying manufacture techniques was not the aim of this work, it was necessary to record the microscopic aspect of the surface before using it (*cf.* Maigrot, 2003). Moreover, although the artifact design does not determine particularities of use-wear (LeMoine, 1991), it conditions its location. Besides, as tools are shaped according to their function (Buc, 2010; Scheinsohn, 2010), we can test the ability of different morpho-functional groups to achieve the mechanical requirements implied in each hypothesis.

Following physical structure of archaeological bone tools, harpoon heads were made on antler (Fig. 5). For drilled points (Fig. 6) and bipoints (Fig. 7), both antler and bone were used. Awls were all made on long bones (Fig. 8a) and smoothers, using *P. granulosus* spines (Fig. 8b; see Table 2).

As *C. elaphus* antler is harder than *B. dichotomus* (used in the archaeological sample) we used modern manufacture techniques such as a metal saw, grinding machine, electric drill and sandpaper. In mammal bone, base-forms were obtained through two different techniques: sawing them with lithic and shell edges[3], or by direct percussion with a hammer stone. For the final shape, bones were scraped with quartzite artifacts, following the archaeological context (1). Finally, as archaeological smoothers were not manufactured, fish spines were used in their natural state.

Finished drilled points, bipoints and harpoons were inserted in wooden shafts (pine -*Pinus*-). Drilled points and bipoints were affixed with Teflon tape (Figs. 6 and 7) and harpoon lines were made with sisal (*Agave sisalana*) strings.

After scraping bone with quartzite artifacts, the tools' edges and ends appear sharp under the ESEM (Fig. 9a). Long, straight, wide and coarse striations can be seen using a stereoscopic microscope (see also Campana, 1989; Newcomer, 1974). Under metallographic microscope, at 50×, we registered inner micro-striations (Fig. 10), typical use-wear left by materials composed of angular grains, such as quartzite (see Averbouh and Provenzano, 1998–1999; Legrand, 2007; LeMoine, 1991). In those cases that we used modern manufacture techniques,

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[3] One secondary aim of the experiment was to test the efficiency of shell edges to saw bones since it would has been a highly available raw material in the study area while lithic materials are locally absent. In our experiment, shell edges were macroscopically modified after 10 min of work because of their brittle nature (very quickly in relation to lithic artifacts). But despite tools seem less sharp at this stage, the accumulated grit acts as an abrasive and made edges more useful (see Buc et al., 2010).

Fig. 4. Natural bone surface: a) *P. granulosus* dorsal fish spine; b) *O. aries* long bone; c) *B. dichotomus* antler.

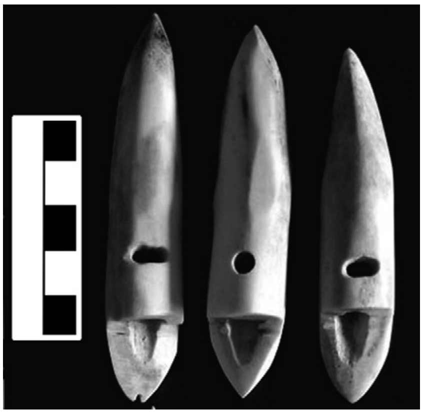

Fig. 5. Experimental harpoon heads.

Fig. 6. Experimental drilled points: a) *C. elaphus* antler; b) *O. aries* metapodial.

Fig. 7. Experimental bipoints: a) *C. elaphus* antler; b) *O. aries* metapodial; c) *C. elaphus* antler.

also longitudinal, long and coarse striations were recorded, though wider than those left by quartzite artifacts.

Sawing marks were also analyzed. As recorded by other authors (D'Errico, 1993; Greenfield, 1999; Liesau von Lettow-Vorbeck, 1998; Walker and Long, 1977), lithic marks are characterized by coarse and deep striations with rough walls; their close V profile can be seen in the ESEM (Fig. 11a). Shell marks, in the other hand, are smooth and have staggered walls with open V profiles (Fig. 11b)[4].

4. Use of experimental tools

Our aim was not to exhaust every functional possibility of the morpho-functional groups, but rather to test the primary hypotheses according to our context of study (see Table 1). The principal aim was to generate a microscopic database of these hypothetical activities. At the same time, we also tested tools' efficiency to meet those mechanical requirements. Experimental tools, activity and materials used are summarized in Table 2.

4.1. Impact

The action involved transversal, local and unidirectional percussion (Fig. 12). In our experiment, this also implied rotation movements to pull the points out of the prey. Two different events were created: direct and indirect impact.

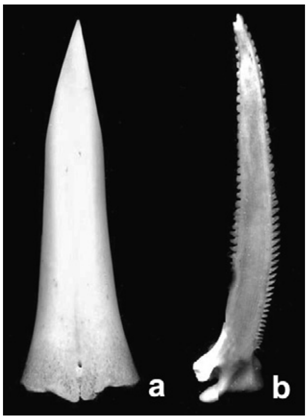

Fig. 8. a) Experimental awl on *O. aries* metapodial; b) Experimental smoother on *P. granulosus* fish spine.

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[4] Our outcomes are different from those presented by Toth and Woods from the same activity (Toth and Woods, 1989: Figs. 4–6) but this might be due to particularities in the experimental program since the authors used shell formal artifacts and we used natural shells (see details in Buc et al., 2010).

Table 2
Experimental database.

	Bone Raw Material	M-F G	Activity	Material	State	Use Time
E4	*O. aries metapodial*	awl	Piercing	Skin	dry	60'
E5	bird	awl	Piercing	Skin	dry	45'
E9	*O. aries femora*	awl	Piercing	Skin	dry	30'
E11	*O. aries humerus*	awl	Piercing	Skin	dry	30'
E16	*O. aries humerus*	awl	Piercing	Skin	dry	30'
E17	*O. aries femora*	awl	Piercing	Skin	dry	30'
E3	*O. aries tibia*	awl	Piercing	Skin	fresh	15'/75'
E2	*O. aries ulna*	awl	Piercing	Skin	wet	45'
E1	*O. aries radius*	awl	Piercing	Skin	fresh	45'
E10	*O. aries splinter*	awl	Piercing	Rushes	fresh	30'
E12	*O. aries splinter*	awl	Piercing	Rushes	fresh	30'
E13	*O. aries splinter*	awl	Piercing	Rushes	fresh	30'
Ai	*P. granulosus spine*	smoother	Smoothing	Pottery medium temper	wet	60'
24d	*P. granulosus spine*	smoother	Alisado	Pottery medium temper	wet	75'
1d	*P. granulosus spine*	smoother	Smoothing	Pottery big temper	wet	30'
Ci	*P. granulosus spine*	smoother	Smoothing	Pottery small temper	wet	60'
P6	*P. granulosus spine*	smoother	Smoothing	Pottery small temper	wet	30'
5d	*P. granulosus spine*	smoother	Smoothing	Pottery big temper	wet	45'
20d	*P. granulosus spine*	smoother	Smoothing	Pottery small temper	wet	30'
2i	*P. granulosus spine*	smoother	Smoothing	Rushes	fresh	30'
E1a	*O. aries splinter*	awl	Smoothing	Rushes	fresh	30'
E4b	*O. aries splinter*	awl	Smoothing	Rushes	fresh	30'/30'
E2a	*O. aries splinter*	awl	Smoothing	Rushes	fresh	30'
E3b	*O. aries splinter*	awl	Smoothing	Rushes	dry	20'
13d	*P. granulosus spine*	smoother	Smoothing	Rushes	fresh	30'
E07-15	*O. aries metapodial*	bipoint	Smoothing	Rushes	wet	15'
19i	*P. granulosus spine*	smoother	Smoothing	Skin	dry	30'
22i	*P. granulosus spine*	smoother	Smoothing	Skin	dry	30'
E1c	*O. aries splinter*	smoother	Smoothing	Skin	wet	45'
E3d	*O. aries splinter*	awl	Hafting	Wood	dry	15 days
E4c	*O. aries splinter*	awl	Hafting	Wood	dry	15 days
E07-2	Antler	harpoon	Direct Impact	Skin & Bones	wet	100 impacts
E07-3	Antler	harpoon	Direct Impact	Skin & Bones	wet	75 impacts
E07-4	Antler	drilled point	Direct Impact	Skin & Bones	wet	50 impacts
E07-7	*O. aries metapodial*	drilled point	Direct Impact	Skin & Bones	wet	34 impacts
E07-11	Antler	bipoint	Indirect Impact	Skin & Bones	wet	5 impacts
E07-12	Antler	bipoint	Indirect Impact	Skin & Bones	wet	1 impact
E07-13	*O. aries metapodial*	bipoint	Indirect Impact	Skin & Bones	wet	21 impacts
E07-14	*O. aries metapodial*	bipoint	Indirect Impact	Skin & Bones	wet	5 impacts

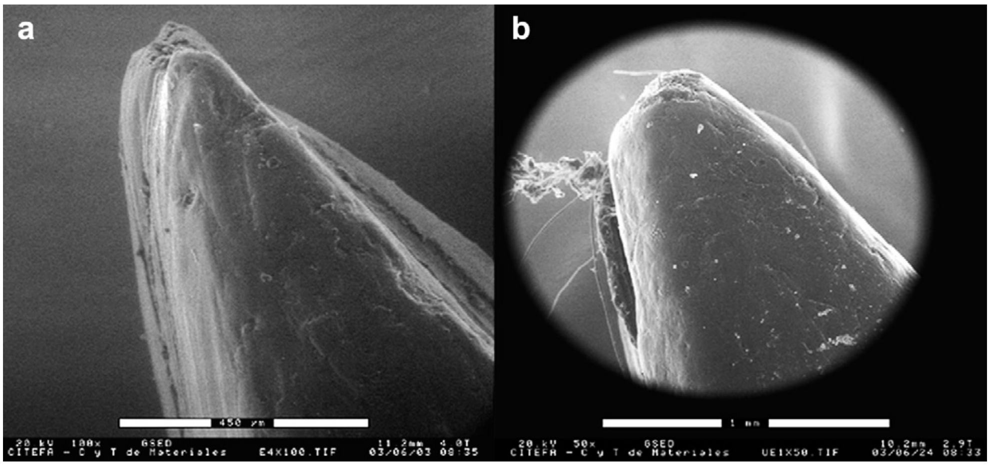

Fig. 9. Experimental awl: a) manufacture traces: sharp lateral and apical end (E4 – 100×, ESEM); b) after skin piercing: rounded lateral and apical end (E1 – 50X, ESEM).

4.1.1. *Direct impact: hafted points used by hand*

4.1.1.1. On fish: Leporinus obtusidens -boga[5]*-.* Given the effect of humidity in use-wear development (see LeMoine, 1991) we kept a wet environment in the experiment by putting water and earth inside a plastic barrel and a wooden structure sustaining the fish (Fig. 13a). In this experiment we used the hafted harpoon heads to hit the bony zones. Although fishers will not seek to impact bony zones, this is a situation more prone to mark antler tools (since bone is harder than soft tissue) which could happen in real conditions.

Despite the fact that real fishing was not replicated, the experiment shows the utility of harpoon heads to hit medium-sized species, as those available in the study area (Musali and Buc, in press). Not only do harpoon heads slide easily across scales, skin and bones, but the detachable system ensures the linkage between fishers and preys for as much time as needed (Fig. 13a).

4.1.1.2. On mammal: O. aries carcass. The mammal carcass was put on the grass. Hafted drilled points were used as spearpoints, seeking to impact on bony zones as in the harpoons' case.

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[5] This is a ray-finned fish, morphologically and structurally similar to *P. lineatus* (sábalo) which is the most frequent fish in the area and can be captured by harpoons (Musali and Buc, in press).

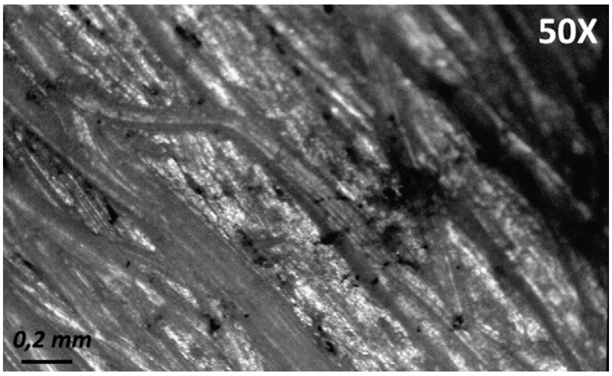

Fig. 10. Bone scraping with quartzite: longitudinal, wide, deep, and coarse striations.

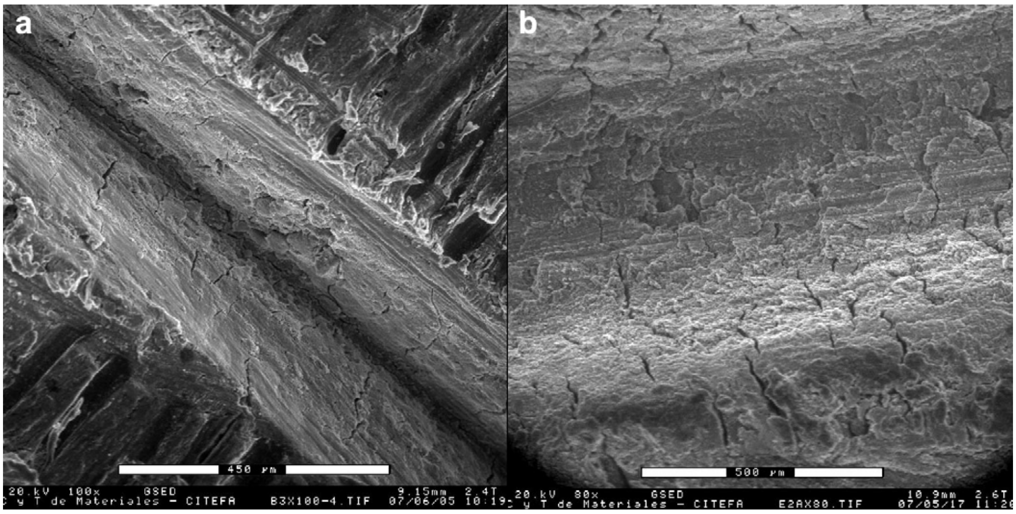

Fig. 11. Sawing marks on bone: a) lithic edge (100×, ESEM); b) shell edge (80×, ESEM).

Even if we did not reproduce real hunting situations, drilled points survived more than 50 impacts without fracturing. One point (E07 7) was detached from the shaft and stayed inside the carcass.

4.1.2. *Indirect impact: hafted points launched with a short bow*

Two different experiments were carried out launching bipoints on arrows with a bow and using an *O. aries* carcass as a target. In the first performance, the carcass was put 8 m away from the archer, sustained 45° from the roof with a tree branch. In the second set of experiments, the carcass was hanged over a straw bundle 12 m away from the archer (Fig. 13b).

Bipoints met the aerodynamic requirements to be launched by a bow (see also Knecht, 1997; Guthrie, 1983). They penetrated the carcass, even in its bony sectors. As in previous impact activities, no macroscopic damage was recorded.

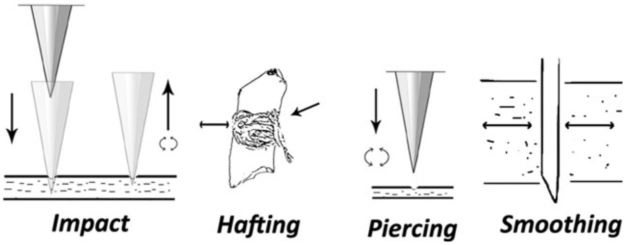

Fig. 12. Experimental actions.

4.2. *Hafting*

If any action involved it was multidirectional pressure, only with short displacements (Fig. 12).

Bone pieces were tied to wooden fragments with sisal strings, and they were carried in a bag for periods of 7 and 15 days. This experiment simulated hafting situations, with the aim of identifying wood use-wear. As no real activity was replicated, we cannot assess the efficiency of the artifact's design.

4.3. *Piercing*

The action involved pressure with bidirectional movements (Fig. 12).

4.3.1. *Skin: M. coypus in dry, fresh and humid (dry and pre-soaked in water) states*

Awls were used to pierce skins from their inner side to make holes. Tools proved to be efficient at this activity. Besides the effectiveness of the apical end in resisting fracture, the articular end acted as a handle. It was useful since skins have grease (even in dry state) and the handle prevents tool's splitting.

4.3.2. *Silica-rich plants: fresh rush (Scirpus californicus)*

No actual basket making was replicated, but piercing movements were made along rushes. For that reason, no estimation about the efficiency of awls in basketry can be made.

4.4. *Smoothing*

The action involved transversal pressure and bidirectional movements with the tool working at an oblique angle (Fig. 12).

4.4.1. *Skin: M. coypus in dry and wet state*

Fish spines were used to scrap the inner part of skins to remove the grease. Tools proved to be efficient for that purpose, and also articular ends were useful since, as in the awl's case, natural grease of bones requires a good handle.

Fig. 13. a) experimental spearing of fish with harpoons; b) experimental launching bipoints arrows with bow.

Table 3
Use-wear results.

Activity	Material	Micro-topography	Micro-relief	Aggregation and distribution of Striations	Morphology of Striations
Impact	Skin, bones	heterogeneous	irregular, rounded high points	no striations	no striations
Hafting	Wood, sisal string	heterogeneous	irregular, flat, smooth high points	cross, random	deep and shallow
Drilling	Skin	homogeneous	rounded, rough high points	distant, cross, transversal	narrow and deep
Drilling	Rush	homogeneous	rounded, flat or rough high points	grouped, parallel, transversal	shallow
Smoothing	Skin	homogeneous	regular, rough high points	cross, transversal	deep
Smoothing	Rush	homogeneous	rounded, rough high points	parallel, transversal	shallow
Smoothing	Pottery	heterogeneous	rounded, flat high points	cross, transversal	deep, variable width

4.4.2. Silica-rich plants: fresh rushes (S. californicus)[6]

In this case we did not replicate a real situation and we just scrapped rushes in their longitudinal axis. For that reason, we cannot test the efficiency of morpho-functional group.

4.4.3. Pottery: wet local clay extracted from Paraná River banks

Fish spines were used as smoothers in pottery manufacture when it was already wet. Since in this kind of experiments tempers are crucial to use-wear (Griffitts, 1993), we used pottery fragments as in archaeological sample (1), trying three different sizes (small, medium, big).

Fish spines behave in an appropriate manner to reduce pottery porosity and articular ends acted as good handles. The resulting pottery has a banded aspect, which is also typical of the local archaeological sample (*cf.* Loponte, 2008).

5. Results

The following information is synthesized in the Table 3.

5.1. Impact

All pieces used in impact activities (direct, indirect; on fish, on mammal) show the same use-wear pattern: although manufacture traces are preserved, the apical ends and general surface are rounded, mainly on its high points (Fig. 14a–b). The micro-topography is heterogeneous and the micro-relief is irregular.

However, two singular cases deserve a detailed mention. In the drilled point that was trapped in target (E07 7) the micro-topography is not rounded (the artifact was subject to few impacts), but it has a short, deep striation, transversally oriented (Fig. 14d). Given that it was the only trace recorded after impact activities, and taking into account the particular use-life of this point, it is possibly that the mark is a result of impact against and perforation of bone.

On the other hand, the bipoint that survived more uses as a projectile (E13, see Table 2) shows high rounding and homogenization of the micro-topography of its apical end with parallel, superficial and narrow striations longitudinally oriented. This pattern is different from those recorded in drilled and harpoon heads, but similar to rush smoothing instead (see 5.4). This point also was used under particular experimental conditions as the target was hanged over a straw bundle, therefore, it is possible that the use-wear is not the result of impact on bone and soft tissue but of the insertion of the bipoint on the straw (Fig. 15).

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[6] One experiment was performed using dry rushes to test use-wear variation, but they were difficult to work.

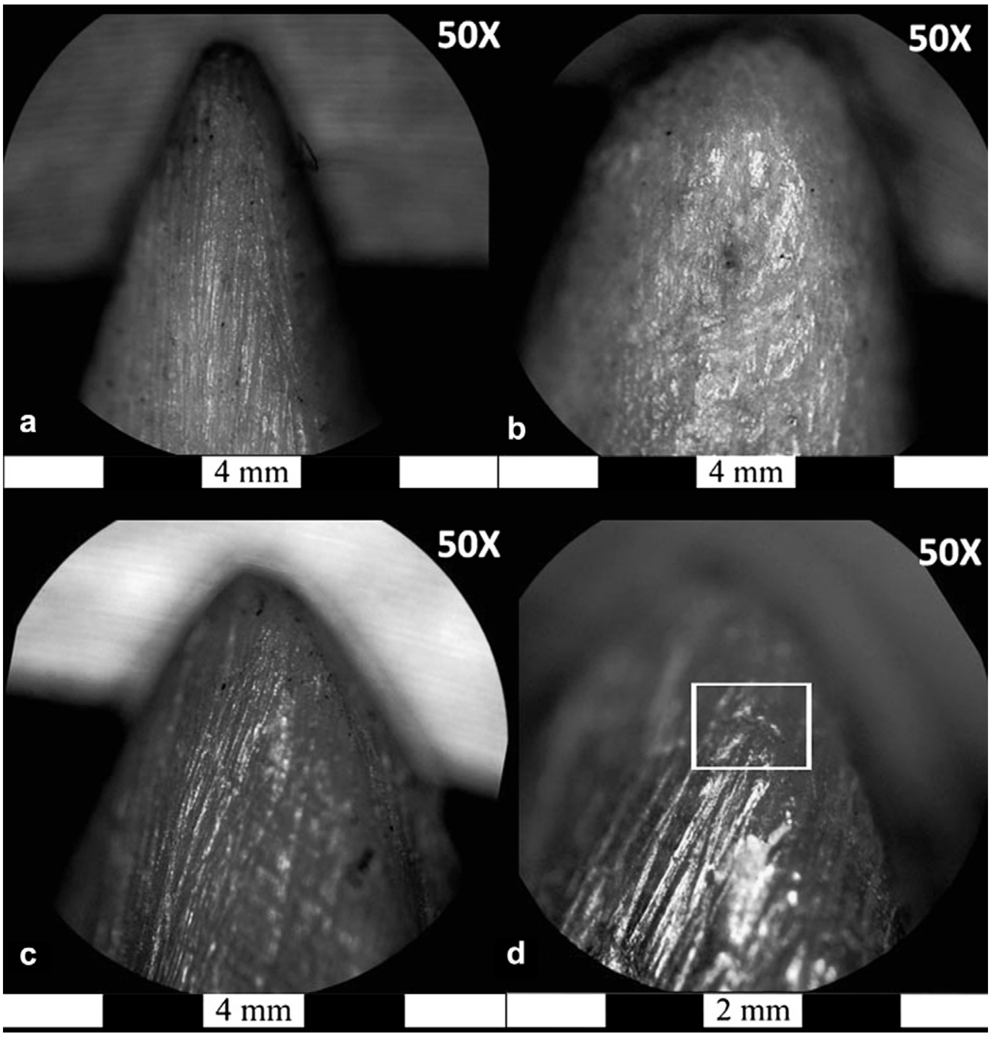

Fig. 14. Impact use-wear. E07-4: a) before use; b) after use: rounding. E07-7: c) before use; d) after use: detail of short, deep trasversally oriented striation.

5.2. Hafting

At 100× the micro-topography appears heterogeneous, and at 200× we can see the irregular micro-relief. High points are flat and smooth with random, crossed, deep and narrow striations (Fig. 16).

5.3. Piercing

In skin and rush piercing, the apical end, lateral sides and faces located 5 cm from the apical end of awls are rounded (clearly seen under the ESEM, see Fig. 9b). Regardless the worked material, at

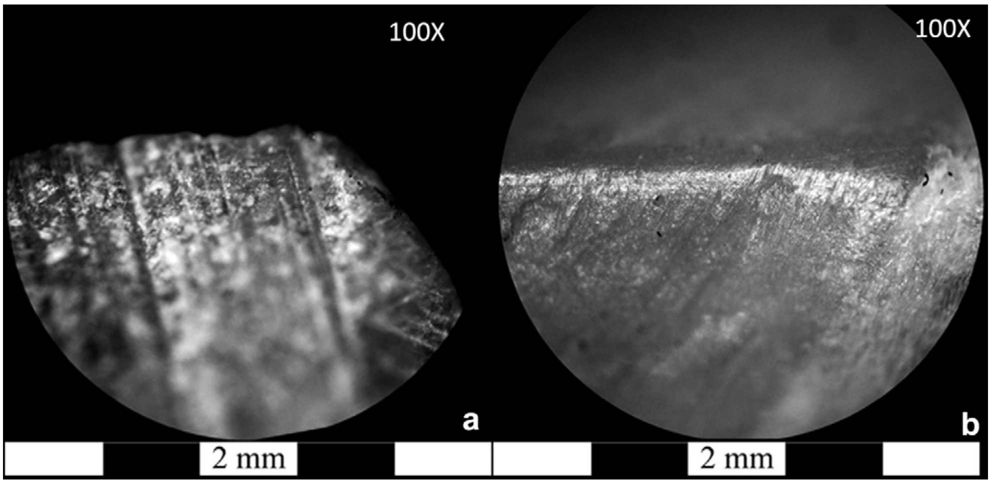

Fig. 15. Bipoint E13: a) before use; b) after use on impact: narrow and shallow longitudinal striations, homogeneous micro-topography.

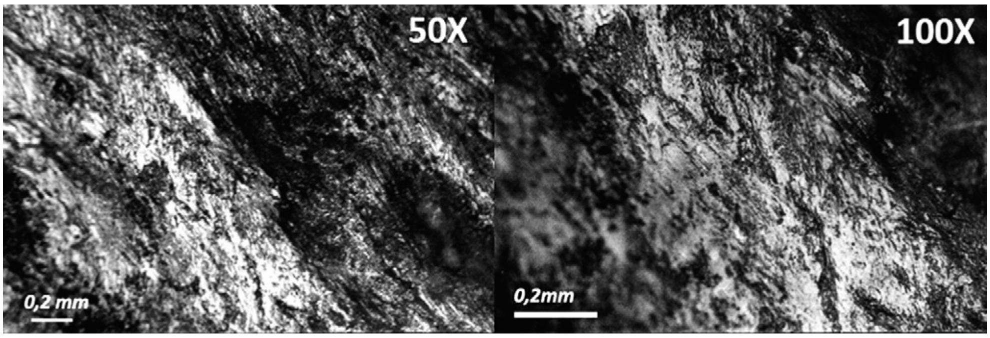

Fig. 16. Hafting use-wear E4c: heterogeneous micro-topography, irregular micro-relief, and flat, smooth high points.

100× micro-topography appears homogeneous in some pieces and heterogeneous in others. After both skin and rushes work, micro-relief can be seen as regular at 200×. In skins, high points appear rough, and after rushes work they are either rough or flat (Fig. 17). Therefore, no specific patterns could be defined according to micro-topography and micro-relief.

Working skins in different states (dry, humid and fresh) result in different patterns of striations (see LeMoine, 1991; Legrand, 2007; Maigrot, 2003). As I have discussed previously (Buc, 2008), in artifacts used for the same amount of time, after working dry skins we can observe deep and close striations, while those resulting from use on humid and fresh skins are more dispersed and shallow. However, I recorded an awl used to pierce fresh skins after 15 and 75 min, and in the latter observation, striations appeared more clustered, similar to the pattern seen after working dry skins 45 min (see Buc, 2008). As LeMoine (1991) stated, lubrication in wet materials reduces wear, so, under the same use time, traces made under wet conditions are developed through a wider surface those of dry materials. Nonetheless, in archaeological tools, where use time is unknown, this fine-scale functional interpretation is impossible.

Despite this fact, differences between rushes and skins are clear in striations, even if they are always transversally oriented due to the piercing activity. In general terms, after skin work, striations are long, deep and crossed (Fig. 17a–b); whereas after rush work, they are short, shallow and parallel (Fig. 17c–d).

5.4. *Smoothing*

After smoothing experiments, the active sectors of tools appear completely flatten to the naked eye. At the microscopic level, wear erases natural bony grooves of natural *P. granulosus* spines (Fig. 4a). Use striations appear transversally oriented but their distribution varies according to the worked material's size.

Differences between materials are seen in micro-relief, as well as in morphology and arrangement of striations.

After working skins, the micro-topography is homogeneous and the micro-relief is regular with both rounded and rough high points. Striations are narrow, smooth, straight, deep and crossed (Fig. 18d–f). Rushes use-wear shows the same aspect in micro-topography and micro-relief than skins; but some pieces have flat high points and striations are very narrow, smooth, straight and parallel, as in awls used on rushes (Fig. 18a–c).

In pottery, micro-topography is heterogeneous (Fig. 18h) but with regular micro-relief, and smooth and flat high zones (Fig. 18i).

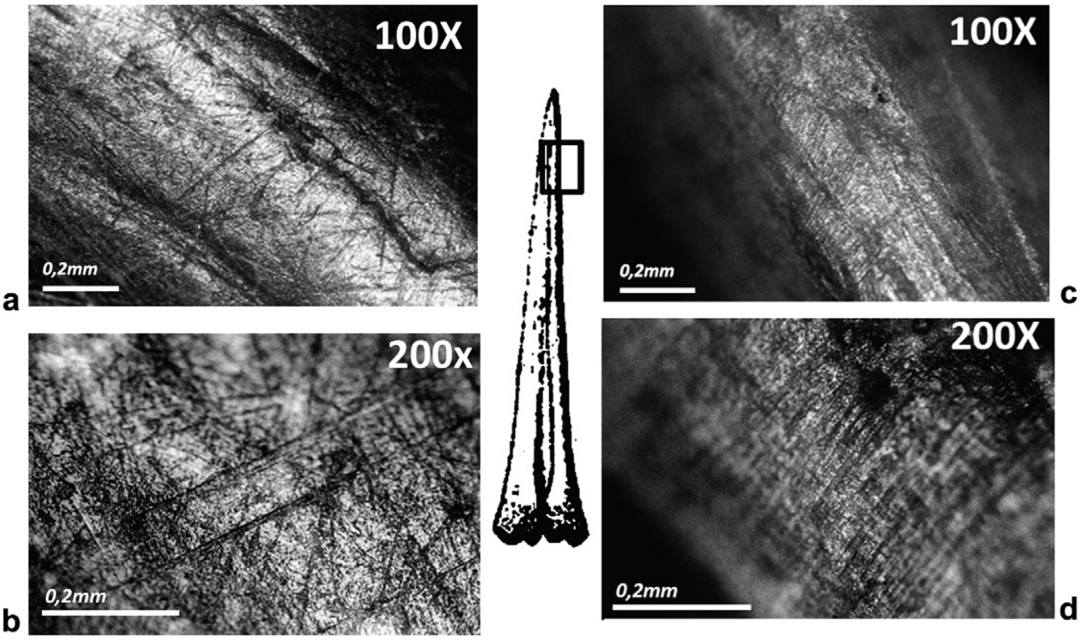

Fig. 17. Piercing. A-b: skin use-wear (E1): a) transversal cross striations, heterogeneous micro-topography; b) homogeneous micro-relief, rough and combed elevations, narrow, deep, smooth striations. C-d: rush use-wear (E12): c) homogeneous micro-topography, transversal and parallel striations; d) regular micro-relief, rounded and rough high points, narrow, shallow, short, smooth striations.

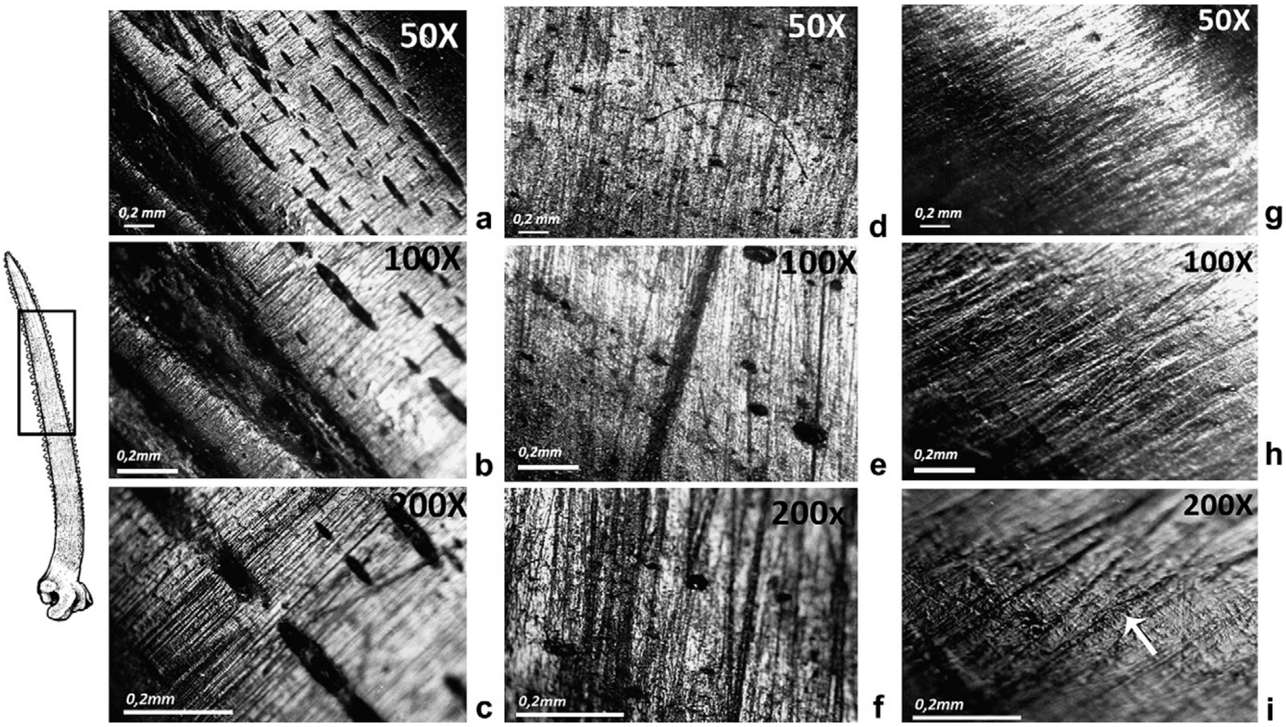

Fig. 18. Smoothing. A-c: rush use-wear (2i): a-b) homogeneous micro-topography, parallel and transversal striations; c) regular micro-relief, rounded and rough high points, narrow, straight, shallow, smooth striations. D-f: Skin use-wear (22i): d-e) heterogeneous micro-topography, crossing and transversal striations; f) regular micro-relief, rounded and rough high points, narrow, straight, deep, smooth striations. G-i: Small tempered pottery use-wear (Ci): g-h) heterogeneous micro-topography, crossed and transversal striations; i) regular micro-relief, plain, smooth high zones, deep, straight striations of variable width (arrow).

Striations are deep, straight, grouped and crossed (Fig. 18i). These striations are generally wide, although they vary according to temper size, which also determines the distance between striations. Logically, in tools used on clay with big tempers, striations are wider and more spaced than those resultant from working pastes with small tempers (see Buc, 2010). However, despite temper size, a typical trait we observed in all pottery cases is that in some striations width varies along their entire length (Fig. 18i).

6. Discussion

Results from the experimental study show that each material and activity could be associated with specific use-wear patterns on bone tools. The arrangement, distribution and morphology of striations are the most diagnostic variables.

The only case where bone showed no striations, and just rounding, was after impact activities. Only one piece which went through an unusual experimental condition shows a deep transversal striation. Although it is possible that this mark were the result of folding bone fibers after impact (*cf*. Arndt and Newcomer, 1986), it was an extraordinary case and, therefore, we cannot view it as a reliable trait of impact. Other authors that performed experimentation on bone projectile points, although not focused on micro-wear analysis, point out that rounding is the only surface modification after impact (Arndt and Newcomer, 1986; Pétillon, 2006; Pokines, 1998; Tyzzer, 1936). Unfortunately, this is a weak comparative trait since it can be the result of non intentional factors as well (*e.g.* post-depositional processes).

After the hafting experiment, we recorded isolated striations and the alteration of high points of the surface. This same use-wear was illustrated by other authors as result of bone use on wood (LeMoine, 1991: 84; see also Griffitts, 2006; Legrand, 2007).

For piercing, the main use-wear is formed by transversal striations distributed all along the apical sector of awls. Differences between skin and rushes are in the depth and arrangement of striations: while in the first case they are deep and crossed, in the latter one, they are shallow and parallel. This same difference was recently recorded by Stone in the analysis of ethnographic samples (Stone, 2010).

After smoothing activities, surfaces are modified in a confined mesial sector, on only one face of the tool. However, this restriction is due to the material's width: wider leaves or narrower skins would result in use-wear extensions unlike to those presented here. Work on rushes and skins produces the same primary difference recorded in piercing activities: shallow and parallel *versus* deep and crossed striations, respectively. These striations also have the same width along their entire length, a situation that can be explained by reference to the elastic nature of the worked materials (skin and rushes) which have regular abrasives (Buc, 2008). On the other hand, striation arrangement is related to the organization of abrasives in worked materials. For example, in animal skins, abrasives (minerals and proteins) are randomly associated (Buc, 2008) and that determines the formation of crossed striations. In silica-rich vegetables as rushes, exterior elements (including phytoliths), are arranged parallel to each other, which is linked with parallel striations seen in bones after use against rushes. This arrangement is diagnostic not only of juncaceous species but of other gramineous plants (Zucol pers. comm.) available in the study area (*cf*. Loponte, 2008); so in further experiments we should broaden the experimental program to include other species.

Moreover, looking at the pictures of other authors' publications, we can see equivalent micro-wear patterns to those presented here after similar experimental conditions; regardless of differences in descriptions (see Griffitts, 2006, Legrand, 2007; LeMoine, 1991; Maigrot, 2003 for skin use-wear; Legrand, 2007 for use on plants). As I followed Legrand's (2007) criteria, her descriptions are comparable, stressing as I did, morphology and disposition of striations as well as micro-topography and micro-relief particularities. In the other hand, Griffitts (2006) points out the difference between skin and plants on surface contours, equivalent to LeMoine's (1991) invasiveness of polish. However, examining Griffitts' illustrations, the non-invasive polish developed after silica-rich plants processing (Griffitts, 2006: 530), is also associated to shallow, usually parallel striations, mentioned in this work as typical trait of rushes; in the other hand, the skin invasive polish (Griffitts, 2006: 523–24) is related with deep, usually crossing striations as seen in the skin experimental sample I presented. Nevertheless, more discussion and work on terms and criteria used is needed in order to compare interpretations of different researchers. Moreover, the database analyzed in this paper must be increased including real situations in order to determine at which extent striation arrangement is determined by activities, as in this opportunity experiments were not real but systematic, precisely, with the aim of recording differences among materials keeping action invariable.

Finally, both skin and pottery produce crossed striation patterns. Differences are evident when comparing big tempered pottery with skin as the former has very wide striations, but small tempered pottery and skin use-wear leave striations that are very similar in width. Distinctions can be made, nonetheless, because small tempered pottery use-wear has deeper, more closely grouped striations than skin and, as mentioned, some pottery striations have a diagnostic trait: they have variable width along their length. As in previous cases, our images are similar to those presented by Griffitts (1993: Fig. 18), Legrand (2007: 224) and Maigrot (2003: 119), despite differences in the raw material used in their experiments. This variation in striations width may be due to plastic deformation of pottery and the action of its irregular temper particles that disintegrate when in contact with bone.

As a final point, we cannot see differences in use-wear between bone raw materials used, including fish and mammal bones. Indeed, we contrasted our results with those of other authors who worked on different bone elements, and use-wear is still comparable. But, although this is true when dealing with bone itself, we can expect variations in the use-wear developed on antler. Since antler material composition is different from bone, it responds in a particular way to stress situations (Guthrie, 1983).

7. Conclusion

Experiments made in bone tools not only help to evaluate their efficiency for to the main proposed uses, but also let us develop a database of use-wear. Reliability on this experimental sample can be increased by comparing our results with those obtained by other authors, which necessarily implies criteria agreements. High quality images and details on microscopes and scales used are also needed in order to overcome particularities in descriptions. Using systematic criteria will let us build additive databases where each works' contribution will be of scientific value, even if it is done in isolation.

In the discussion of this paper, I also attempted to deal with use-wear formation in more theoretical terms trying to understand the singular morphology and distribution of striations by the nature of worked materials and their abrasives. This is a methodological path that needs more fieldwork but it promise to make experimental databases more consistent at the moment to test use in archaeological tools.

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