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Reconstructing Magdalenian hunting equipment through experimentation and functional analysis of backed bladelets

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Abstract

The hunting technical sphere has a particularly important socioeconomic role among hunter-gatherers as it provides vital nutritive goods and serves numerous technical spheres. Approaching Upper Palaeolithic hunting techniques therefore offers a valuable insight into past cultural dynamics. Microliths are often the only conserved evidence of Magdalenian hunting equipment, occasionally accompanied by osseous projectile points to which they were exceptionally found hafted. Backed bladelets are the most common Magdalenian microliths. In this paper, we investigate their function as projectile insert, and address the question of projectiles designs through the analysis of impact damages. In this perspective, we implemented three experimentations including manufacturing, trampling and use of backed bladelets as projectile inserts. Results show distinctive combinations of damages between each three experimentations, allowing to reinforce the damaging pattern of lateral flint inserts and to discriminate lateral scars specific to the impact. The functional analysis of backed bladelets from two Early Middle Magdalenian sites located in west-central France (La Marche and the Blanchard cave) shows that these tools were specifically used as projectile inserts. The bladelets impact damage patterns are different between the two sites and match differences of morphologies of antler projectile points. The systemic reasoning carried out allows evidencing variations of hunting technical behaviours that were not, until then, perceived through the comparison of production techniques and typology of microlith assemblages of west-central France.

Key-words

Upper Palaeolithic, Magdalenian, Hunting equipment, Experimentation, Lithic industry, Functional Analysis.

1. Introduction

Backed bladelets are amongst the most common tools of the European Upper Palaeolithic, particularly during the Magdalenian. At this period their production techniques and typology enable following rapid transformations and regional variations of the socioeconomic systems (e.g.

Bosselin and Djindjian 1988; Ducasse and Langlais 2007; Langlais 2007; Langlais *et al.* 2016; Sécher 2017). Investigating the function of these microliths could allow participating in the understanding of complex cultural phenomena.

Exceptional Magdalenian exemplars of points armed with lithic inserts from Pincevent and the Blanchard cave at la Garenne show that bladelets functioned together with antler projectile points (Fig. 1, Allain and Descouts, 1957; Leroi-Gourhan, 1983). The morphology and production techniques of antler points are also strong markers of the Magdalenian technical variations and transformations (e.g. Breuil 1912; 1954; Malgarini 2014; Pétilion 2016).

Such composite projectiles put into system osseous points and microlithic elements, which are two robust cultural markers of the Upper Palaeolithic. While the antler point supports the lithic inserts, absorbs most of the impact violence, and can initiate the perforation of the target, the lithic inserts receive part of the shock, may go on perforating the target, and tearing/slashing it. The efficiency and the performance of composite projectiles associating antler points and backed bladelets have been demonstrated experimentally (Pétilion *et al.*, 2011).

Backed bladelets are composed of a straight retouched back and a long low-angle linear cutting edge opposed to it, which is generally unretouched and constitutes a vulnerable part that may suffer important damages. Impact damages include fractures (i.e. developed from one lateral edge to the other or one surface to the other, Coppe and Rots, 2017), lateral scars (i.e. developed on a surface from a lateral edge), and linear impact traces or striations. These damages are most often the only way to reach the function of Palaeolithic projectiles and the complex hunting technical sphere. In several European Magdalenian sites, the analysis of impact damages has thereby allowed to demonstrate that backed bladelets were primarily used as projectile inserts (Christensen and Valentin, 2004; Clemente Conte *et al.*, 2017; Ibáñez Estévez 1993; Taller *et al.*, 2012; Sano, 2009; Symens 1986).

Backed bladelets from the Early Middle Magdalenian (EMM, 19,5-17,5 ka cal BP, Langlais *et al.* 2016; Pétilion 2016; Sécher 2020) sites of La Marche (Vienne, France) and the Blanchard cave at la Garenne (Indre, France) are by far the best-represented tools and are often damaged. Preliminary observation of the damages on the backed bladelets from both sites shows that they were used as projectile inserts (Gauvrit Roux, 2019; Gauvrit Roux and Beyries, 2020; see part 7.). But is it possible to go further in the functional interpretation, notably regarding their position on projectiles?

Use-wear analysis of backed bladelets faces two gaps: first, experiments of use of composite projectile replicas are scarce and, in each case, few damages of use have developed on the hafted bladelets (Moss and Newcomer, 1982; Pétilion *et al.*, 2011; Wood and Fitzhugh, 2018). Secondly, although functional interpretations must combine all traces to be valid, the interpretative frame for identifying projectile inserts rests mainly on diagnostic impact fractures (DIF), to a lesser extent on microscopic linear impact traces (MLIT), and rarely considers lateral impact scars (LIS). However, scars are often the only type of damage on the archaeological backed bladelets, and may be the only use-wear allowing access to their function.

To investigate microliths function and address the question of projectile designs, we implemented a set of three experimentations including manufacturing, trampling and use of backed bladelets as projectile inserts. Our objective was to participate in developing a methodological frame for the functional analysis of damages on the lithic projectile inserts with a specific focus on lateral scars, in order to better interpret function and functioning of Magdalenian backed bladelets. Besides projectile use, several formation processes may harm

microliths: manufacture, alteration, and a variety of activities. Discriminating between damage causes requires a solid methodological base which mostly relies on experimental data. We therefore searched for criteria discriminating impact wears from those occurring in other situations (i.e. manufacturing and trampling), as damages are diagnostic of impact only if compared to other formation processes (Chesnaux, 2014; Rots and Plisson, 2014).

2. Archaeological material

West-central France is at the crossroad of at least two EMM technical traditions which are mostly contemporaneous during the Late Glacial (e.g. Kozłowski, 1984; Sécher, 2020), and both produced truncated backed bladelets. The Lussac-Angles Magdalenian is specifically defined from the eponym short lanceolate point which is single-bevelled, bears one or two grooves, and is found from the Paris basin to the north of Spain (Pinçon, 1988). A rich art and ornaments production is associated with these antler projectile points (Dujardin and Pincon, 2000; Bourdier, 2010; Fuentes, 2013; Bourdier *et al.*, 2017). The Navettes Magdalenian is defined from a set of art, ornament and bone industry productions including navettes and long single- or double-bevelled antler points with or without groove, found from Gironde to Poland (Allain, 1957a; Allain *et al.*, 1985; Houmard, 2003a; Bourdier *et al.*, 2017).

We investigate the function of EMM backed bladelets through two sites at the historiographical centre of the definition of these technical traditions: La Marche for the Lussac-Angles Magdalenian and the Blanchard cave for the Navettes Magdalenian. They are located in West-central France, south of the Paris basin, in a region of plains with large open valleys (Fig. 2). They are close geographically and were occupied during the cold and wet first phase of the Heinrich 1 event (Stanford *et al.*, 2011; Rasmussen *et al.*, 2014; Naughton *et al.*, 2016). Both caves are oriented south and overlook a watercourse. The best represented fauna taxa are horse and reindeer and secondary taxa notably include bovids and saiga antelope (Pradel, 1958; Bayle *et al.*, 2009).

La Marche cave was first excavated in 1937 (Péricard and Lwoff, 1940; Lwoff, 1989); the last field operation (1988-1993) consisted in sieving previous excavation material, uncovering numerous bladelets (Airvaux, 2001). The main stratigraphic unit is a palimpsest of EMM occupations dated from 18,2 to 17,3 ka cal BP (means of the beginning and ending occupation phases from Chronomodel Bayesian modelling, after ^{14}C dates from Barshay-Szmidt *et al.* 2016; Brou *et al.* unpublished; Pradel 1980; Fig. 3; Table 1). It yielded over 10 000 lithic artefacts including about 45 % backed bladelets.

The Blanchard cave was discovered in 1956 and excavated from then until 1976 (Allain, 1957b; 1984). It is located on the hillside of la Garenne, immediately underneath the Grand Abri rock shelter, which is partly attributed to the Navettes Magdalenian. The occupation of the Blanchard cave is often interpreted as being directly anterior to the Grand Abri one, because their stratigraphy joins south (Allain and Descouts, 1957; Allain *et al.*, 1985; Despriée *et al.*, 2009). The four ^{14}C ages obtained on the eldest layers of the Blanchard cave (i.e. B6 to B4) are coherent with the EMM: the mean of the beginning phase is 18,6 ka cal BP and the mean of the ending phase is 18,1 ka cal BP (Chronomodel Bayesian modelling, after ^{14}C dates from Despriée *et al.* 2009; Fig. 3; Table 1). The youngest layers (i.e. B3 to B1) of this multi-layered site are also attributed to the Navettes Magdalenian (Allain *et al.*, 1985), but they are not yet dated. They are logically younger than layers B6-B4 and could therefore show higher contemporaneity of the site with the EMM

occupation at La Marche. The Blanchard cave yielded 11 735 lithic artefacts (counts P. Paillet, unpublished), with 21 % backed bladelets.

Morphological differences between the antler points from La Marche and the Blanchard Cave are at the heart of the identification of distinct EMM technical traditions (Fig. 4, Allain *et al.* 1985; Bourdier 2010; Pétilion 2016; Pinçon 1988; Sécher 2017). Intra-site variations superimpose upon the inter-site ones: the rich osseous industry assemblage from la Marche not only includes Lussac-Angles points but also other types of points with a longer shaft, for example; these lasts remain to be studied (A. Astier, pers. com.). Likewise, at the Blanchard cave, the corpus of projectile heads includes a wide variety of points; their base can be single- or double-bevelled or conical and they can wear grooves of varying depth or short and thin incisions (Allain *et al.*, 1985; Chauvière and Rigaud, 2009; Houmard, 2003a).

Bladelets from both sites are made of allochthonous fine-grained flints, mostly Upper Turonian from the Grand-Pressigny region and Lower Turonian from the Indre and Cher Valleys, whose sources are located south of the Paris basin (Aubry, 2003; Primault, 2003). Bladelets were produced according to a wide variety of arrangements (Jacquot, 2002; Taylor, 2003; Airvaux *et al.*, 2012; Gauvrit Roux and Beyries, 2020). Whether it be with a unipolar or a preferential unipolar rhythm, on the wide or narrow flaking surface of a block, on the slice of a large flake or on the surface of a blade, with a semi-rotating, rotating or frontal exploitation pattern, the obtained blanks are rectilinear with parallel edges and generally have low-angled lateral edges. They are devoted to highly standardised backed bladelets manufacturing whose back is straight, not lateralised, generally abrupt and invasive (Fig. 5). They are occasionally truncated or appointed by retouch; marginal double backing is relatively frequent at the Blanchard cave (46 %), much less at La Marche (3 %).

The EMM backed bladelets from la Marche and the Blanchard cave only show traces of use as projectile inserts (i.e. impact fractures, scars and striations; see Gauvrit Roux, 2019; Gauvrit Roux and Beyries 2020, and part 7.). Besides projectile insert use, other uses such as scraping, cutting or piercing could be expected in Magdalenian context, as evidenced in Hohle Fels in Germany (Taller *et al.* 2012), in Verberie and Étiolles in the Paris basin (Christensen and Valentin 2004; Symens 1986), or in Praileaitz (Clemente Conte *et al.* 2017) and Santa Catalina (Ibáñez Estévez 1993) in the Spanish Basque Country. Scars, rounding, shine, polish and striations related to motions such as cutting or scraping are however absent from the analysed EMM backed bladelets. This absence can be due to the weak development of traces (e.g. low intensity activities, soft materials working), or to the specialized function of backed bladelets as projectile inserts in the studied sites. As a consequence, we only tested the use of backed bladelets as projectile inserts.

3. Use-wears observation methods

Sampling was necessary considering the quantity of bladelets in each site. We selected 356 microliths (La Marche = 183; the Blanchard cave B2-B6 = 173) based on macroscopic wears (i.e. fractures, scars, residues, rounding, shine, striations) using binoculars Olympus ($\times 15,3$ - $\times 76,5$), MFU MBS-10 ($\times 4,8$ - $\times 98$), and a Dino-Lite digital microscope (Dino-Lite Digital Microscope Premier, $\times 30$ - $\times 250$).

Both archaeological and experimental bladelets were observed with the naked eye and binocular (Olympus SZ ET, $\times 1$ - $\times 6.3$ and Leica Z16 APO, $\times 0.57$ - $\times 9.2$). Pieces presenting

macro-wears were observed under reflected light optical microscope (Leica DMRM, $\times 100$ - $\times 200$) to characterise polish and striations. Every type of damage was recorded.

We cleaned pieces with no residue under tepid running water using a soft toothbrush and soap, then we locally applied 90° alcohol; this protocol aimed at removing sediment or grease remains from the surface of flints.

The identification and the terminology of DIF is based on the methodologies developed by A. Fischer *et al.* (1984) and L. Chesnaux (2014). DIF include the burination fractures, bending initiated fractures and spin-off fractures that exceed 2 mm length and are posterior to manufacture (Fig. 6). We distinguished the facial spin-off from the burination spin-off (Chesnaux, 2014). Both are secondary scars that extend from a fracture; the first develops on a face, whereas the second develops on an edge. Snap and cone fractures were not considered to be diagnostic of the impact because experimental models show that they can be due to other processes than the use of microliths as projectile inserts.

The description of scars includes several criteria: their initiation type (i.e. bending, cone, snap), initiation depth (i.e. shallow or deep), disposition (i.e. isolated, aligned, overlapped), orientation (i.e. perpendicular or oblique to the edge), inclination (i.e. abrupt, semi-abrupt, grazing), morphology (i.e. half-moon, semi-circular, triangular, trapezoidal, quadrangular, irregular), termination (i.e. feather, hinge, step, snap), location (e.g. proximal left, distal right), position (i.e. the face or the faces of the blank), length and width (Hayden, 1979; Vaughan, 1981; Ibáñez Estévez and González Urquijo, 1994; Fig.7).

4. Experimental protocol

The experimental protocol is built from observations made on the archaeological record to respect morphological, technological and mechanical properties of backed bladelets and projectiles from the studied sites. When no direct information could be inferred from this material, the experimental units are based upon previous experimentations of composite projectile use and ethnoarchaeological observations (e.g. adhesives composition, shooting distance). The experimental units are stated and justified hereinbelow.

4.1. Bladelets manufacturing experimentation

The backed bladelets manufacturing experimentation combines the analysis of knapping and retouching damages of 181 EMM backed bladelets replicas.

Bladelets were knapped by the experimented flint knapper researcher M.-I. Cattin by direct percussion with a reindeer antler hammer. She exploited several types of fine-grained flints: Bergeracois from Dordogne (France), Upper Turonian from the Grand-Pressigny region, Campanian from the north of the Paris basin and Kimmeridgian from Switzerland. Flint cores were knapped according to a unipolar semi-rotating method; their flaked surface was wide and careened. The obtained bladelets show acute lateral edge angles (25-30°) and most often have a straight profile (70 %), with a trapezoidal or less commonly triangular section. Some bladelets were transported together after knapping because not all of them could be knapped at once.

M.-I. Cattin and E. Gauvrit Roux retouched the bladelets using antler pressure (rarely soft stone pressure) on antler anvil or occasionally on the thigh. Retouch is marginal to very invasive, direct, and shapes an abrupt rectilinear back on the whole length of blanks. Several of them were appointed to improve their penetration potential. Blanks were occasionally fractured by hand pressure or truncated (N = 10) to homogenise their size or rectify the curve of their profile.

The average length of the obtained backed bladelets is 21,4 mm (σ 9,3 mm), their average width is 9,1 mm (σ 2,5 mm) and their average thickness is 2,6 mm (σ 1 mm).

4.2. Trampling experimentation

Two alternating persons (55 and 60 kg) wearing leather moccasins trampled 45 bladelets for 1h30 in a 4 m² experimental surface composed of clay organic sediment with abundant limestone gravels and blocks. Thirty-five bladelets were covered by 2 cm of sediment and 10 were left on the surface. The square was excavated after trampling and the sediment was dry-sieved with 5 mm mesh sieves. One bladelet could not be recovered out of the 45 experimental pieces.

4.3. Experimental composite projectiles shooting

The experimental shooting of composite projectiles requires a heavy and rigorous protocol as it puts into system several units which need to be well-prepared and controlled for the good proceedings of the experimentation.

4.3.1. Backed bladelets and projectile head designs

Replicas of 84 EMM backed bladelets were hafted to 24 projectile points to document damages related to their use as lateral inserts.

We tested four projectile head designs; in the first three cases three inserts were hafted in each groove (Fig. 8, n°1, 2, 3) and in the fourth design (Fig. 8, n°4), one single insert was hafted; the unretouched lateral edge was always sub-parallel to the projectile head (Table 2).

Part of the backed bladelets have parallel lateral edges and no point. They present a rectilinear longitudinal sharp edge capable of tearing/slashing. Another part of the bladelets present a lateral edge converging towards the rectilinear back, most often because the blank itself was convergent and occasionally because it was appointed by retouch. Those microliths have an axial or tilted point capable of piercing and a rectilinear longitudinal sharp edge that may tear/slash (according to the morpho-technic categories of L. Chesnaux, 2014). Pointed pieces were positioned as head bladelets on projectiles and, as far as possible, as mesial and tail inserts in the second and third points designs. This choice was based on the results of the experimentation of J.-M. Pétilion *et al.* (2011) who underline the necessity to cautiously select head lateral inserts because of their role and of the physical constraints exerted on them: their tearing/slashing edge must be regular and the inserts rather pointed to penetrate the prey and not be ejected at the impact.

4.3.2. Antler points

The 24 EMM projectile head replicas were made of reindeer antler as in most Magdalenian contexts (Bellier and Cattelain, 1990; Houmard, 2003a; 2003b; 2009; Pétilion *et al.*, 2011; Pétilion, 2006, 2016).

We used replicas of the two most frequent single-bevelled archaeological points. They were conceived to represent part of the archaeological variability: morphology and dimensions of one group of points (N = 15) are close to the short single-bevelled lanceolate points of Lussac-Angles (head designs 1, 2, 3). The second group of experimental points (N = 9) is similar to long single-bevelled points from the Blanchard cave (head design 4). Each point bears two opposed longitudinal grooves with a symmetric V section (Fig. 9, Table 3).

4.3.3. Wooden shafts

The use of rectilinear, relatively dense and resistant shafts conditions the equilibrium of the projectile, as well as the precision and the effectiveness of the shot (Cattelain, 1994; Pétilion, 2006). Besides, a heavy projectile hardly deflects its trajectory in case of wind and penetrates the target more easily because of inertia. We used 2 m long and 14 mm diameter industrial pine (N = 15) and fir (N = 9) dowels as shafts. Besides the good representation of pine in the palynological data from La Marche and the Blanchard cave (Leroi-Gourhan, 1973; Renault-Miskowsky and Fellag, 2009), we used industrial dowels because of their regularity, equilibrium and pragmatic availability in commerce.

Each shaft was fletched with two halves of goose feathers fixed with industrial glue to stabilise the trajectory of projectiles.

4.3.4. Hafting arrangements

- **Inserts positioning**

We favoured the lateral position of bladelets over the axial (i.e. point) or disto-lateral (i.e. near the point) ones based on the Magdalenian examples of conserved points armed with microliths from Pincevent and the Blanchard cave (Allain and Descouts, 1957; Leroi-Gourhan, 1983). In the first case, two bladelets are fixed with glue on each side of the distal extremity of an antler point, and in the second case, the groove of an antler point is filled with flint fragments that may correspond to several fragmented bladelets.

In addition, we wanted to participate in filling the scarcity of experimental frame of reference for the lateral position of flint projectile inserts (Moss and Newcomer, 1982; O'Farrell, 1996; Pétilion *et al.*, 2011; Chesnaux, 2014).

Microliths were positioned in the antler points grooves according to the composite projectile head from Pincevent (Leroi-Gourhan, 1983): flint inserts were on the same plane (Houmard and Jacquot, 2009).

Short Lussac-Angles replica points have short grooves in which a single bladelet was inserted (head design 4). On the contrary, the Blanchard cave replica points have longer grooves in which several bladelets were inserted (head designs 1, 2, 3) (Fig. 10).

- **Lateral inserts fixation**

The adhesive that fixes the lithic inserts conditions their reaction to impact. If the glue mix is too soft or too brittle, it distorts or breaks, and inserts can be ejected (Pétilion *et al.*, 2011; Chesnaux, 2014). The functional efficiency of a mix composed of colophony (20-30 %) and beeswax (70-80 %) is demonstrated experimentally as it deforms and absorbs the impact constraint (Chesnaux, 2014).

We used a hafting adhesive composed of colophony (30-40 %), beeswax (60-70 %) and Villecroze bauxite powder (5-10 %). The addition of mineral to the glue was based on two elements: first, archaeological microliths present residues partly composed of iron oxide that may correspond to hafting glue (see part 6.5.4.). Second, adding a mineral load to the glue mix favours linking the different composing elements (Salomon, 2009; Chesnaux, 2014; Pradeau, 2015).

- **Antler points hafting**

Single-bevelled antler points were hafted to single-bevelled wooden shafts using a protocol developed by J.-M. Pétillon (2006) who applied rabbit skin glue on the contact zone between the antler point and the shaft (i.e. the single bevels) and on the distal part of the shaft and the proximal part of the antler point. We detached beef, sheep and pork tendons from fresh bones, taken apart by percussion with a hard stone pebble on hard stone, and soaked into water. Moist tendons were coiled around both shaft and point, a long way from the bevels contact zone to maximise hafting resistance. We applied rabbit skin glue on the tendons and the arrangement was eventually air-dried.

The long bevel of Lussac-Angles points (36,7 mm on average, which is about the half of their average length, Fig. 9 and Pinçon, 1988) facilitates its hafting to the shaft as the contact zone is particularly large; it may also make the hafting more resistant than shorter bevels.

- **Projectiles dimensions and weight**

The average diameter of projectiles (including shaft, antler point and lithic inserts) is 27 mm (σ 3 mm) and their average length is 206 mm (σ 4 mm). Average weight of projectiles with pine shaft is 135 g (σ 10 g) and 187 g (σ 17 g) for fir shafts.

4.3.5. Shooting parameters

The experimentation took place in a fallow field under temperatures varying between 15° and 23°C. The target was the complete carcass of a young sheep (*Ovis aries*) slaughtered just before the experimentation. It was hung to a wooden structure in a lifelike position by ropes passing under the head, and the anterior and posterior limbs (Chesnaux, 2014). A plastic tarpaulin was placed between the target and the ground for an easier recovery of microliths (Pétillon *et al.*, 2011).

Projectiles were propelled with a spear-thrower by an experimented shooter (I. Yahemdi from the Préhistotir association); the firsts spear-throwers are indeed attributed to the Cantabrian Lower Magdalenian and the EMM (type 2a), with one specimen from the Blanchard cave (Fig. 11, Cattelain 1978; 2017; Cattelain and Pétillon, 2015). The position of the shooter was frontal or oblique to the target and the shooting distance was set at 10 m and adapted at 8 m. The shots were aimed at the bones (rib cage, head); each projectile was shot once and ten undamaged projectiles were shot twice.

The carcass was butchered after the shots to find back the microliths prisoner in it and to extract and document impacted bones.

5. Experimental results

5.1. Manufacturing

Manufacturing damages affect 81 % of the bladelets. Extremity fractures are the most frequent damage type (73 %), followed by scars (15 %) and microwears (9 %) (Table 4).

Knapping fractures occurred when the knapper held back the bladelet, blocking the diffusion of the shock waves which reverberated in the blank, eventually causing a fracture. They also occurred when the percussion strength was not adapted to the fragility of the raw material.

Retouch fractures occurred when more or less curved bladelets were submitted to pressure against a plane surface of the antler.

Part of the fractures is intentional; their snap section and the absence of impact point prevent from distinguishing them from snap fractures occurring in other steps of the manufacturing process.

Fractures generally have a snap section (55 %) or a bending initiation (42 %). In most cases their length ≤ 2 mm (90 %). Bending fractures whose length > 2 mm could be confused with DIF in the archaeological record, if not for the chronology between retouch and fracture. Distinguishing between long bending knapping fracture and DIF is however complicated in cases of refraction (Chesnaux, 2014).

Most frequent microwears are rounding, polish and striations of the butt due to abrasion of the overhang, and striations due to edge backing. Some pieces present bright spots and slight rounding of the prominences caused by friction between pieces due to storage between knapping sequences.

Numerous bladelets have scarred butts (9 %) which can be due to the trajectory of the hammer, the strength of the stroke, the raw material, the style of the knapper, the insufficiency of preparation of the striking platform. This stigma is more often recognised for soft stone than direct organic percussion (Pelegrin, 2000), which underlines the need to be cautious when determining knapping techniques.

We identified three types of manufacturing scars on the lateral edges (Fig. 12). They are abrupt or semi-abrupt, not invasive, medium or small-sized (≤ 1 mm) and none is accompanied with an edge crushing. The first category includes scars with a bending initiation. They are aligned, perpendicular to the edge and inverse, most often have a semi-circular morphology, with a hinge or a feather termination. These are frequent (41 %) and are related to pressured retouch; they differ from spontaneous retouch (Newcomer, 1976) which is direct and caused by knapping. The second category gathers scars that are cone initiated, isolated, perpendicular or slightly oblique to the edge, and have a semi-circular morphology with a hinged termination. The third category brings together crescent break scars with a snap section and a half-moon morphology found isolated or aligned.

5.2. Trampling

Trampling damages affect 48 % of the experimental bladelets. Lateral scars are the most frequent damages (45 %), followed by fractures (20 %) and microwears (16 %). Surface bladelets were much more damaged than those buried under 2 cm of sediment (Table 5):

Eight of the nine fractured bladelets were on the surface. Six bladelets fractured in two pieces, and three in three pieces. Nine fractures have a snap section and three have a bending initiation with a feather or a hinge termination. These are generally short (< 1 mm) but on one microlith it is 2,5 cm long and its characteristics are similar to DIF. The studied sample is too reduced to question the 2 mm DIF limit for backed bladelets, underlining the necessity for further experimentations.

Microwears are mostly developed on the prominent parts of bladelets and do not show a preferential orientation. Striations and islets of relatively flat polish developed on or away from

edges or ridges. Striations are varied and can have a rough or smooth bottom, or be additive. Overlapped small scars can be associated to rounding of the prominences.

Four categories of edge scars are distinguished. They are abrupt or semi-abrupt, generally not invasive and are medium or small-sized (Fig. 13). Two morphologies of isolated scars are identified: the first category, scars have a deep cone initiation, they are perpendicular to the edge, have a semi-circular morphology and a feather or a hinge termination. In the second category, scars have a bending initiation which is not deep, they are oblique, have a triangular morphology and are step terminated. The third category gathers overlapped scars with a deep cone initiation that can form pseudo-notches (Prost, 1988; McBrearty *et al.*, 1998; Claud, 2008); they are the most frequent (42 %), often show crushing of the edge and are perpendicular or slightly oblique to the edge. They have varied morphologies and terminations. The fourth category gathers crescent break scars with a snap section and a half-moon morphology found isolated or aligned.

5.3. Experimental use of projectiles

5.3.1. The behaviour of projectiles

Projectiles shot with spear-throwers suffer important torsions during their trajectory: while flying, they curve in one way and the other with one centred torsion point; the highest torsions occur at impact, with one or two torsion points and more pronounced curvature (Fig. 14, Fig. 15). The fracturing of mesial parts of shafts caused by these torsions and the reconstitution of the behaviour of projectiles underline the importance for the shaft to be flexible to absorb the mechanical constraints.

5.3.2. Damages to the target

Seventeen of the 34 shot projectiles reached the target and seven penetrated it. Fourteen missed or slipped shots impacted the sediment, occasionally through the tarpaulin or the ropes. Two microliths were lost after missing the shots.

Four projectiles reached the head (two penetrating it, both in contact with the cranium) and 12 reached the rib cage or the belly (five penetrating them, with three in contact with the ribs). Three microliths remained prisoners in the carcass after removing the projectile: one head bladelet in the cranium and two mesial bladelets in the rib cage.

The low-frequency of shots reaching the target is attributed to two elements: the shooter was not used to the weight and equilibrium of the projectiles, and a light wind slightly deflected the light fir shafts, which is the reason why he adopted an oblique position to the target. The cattle farmer did not follow our instruction to shave the sheep before the experimentation and projectiles often bounced against the short haired wool, hence the low frequency of penetrating shots and the low penetration depths (maximum 11,5 cm). Only the heaviest projectiles (175-200 g) did not bounce, most often reached the target and penetrated it, as inertia and kinetic energy are correlated to the mass of projectiles (Carrère, 1990). Previous experimentation of spear-thrower shooting of composite projectiles showed higher penetration depths (28,3 cm average, Pétilion *et al.*, 2011).

Penetrating projectiles caused lacerations which were on average 3,5 cm exterior width, ranging from 5 cm to 2,7 cm.

5.3.3. Antler points damages

Half of the antler points present impact damages (Table 6). The crushing of the tip occurred after missed or bounced shots. Crushing with short fracturing occurred after missed or penetrating shots. Short fracturing of the points occurred in every instance (i.e. penetrated, bounced, slipped, and missed shot) and one long embryonic bevel fracture occurred after a missed shot.

The crushing of points goes along with the fracturing of bladelets in two cases, and in 18 cases the point crushing and/or fracturing goes along with bladelet scarring (Fig. 16).

5.3.4. Backed bladelets damages

Impact damages affect 38 % of the bladelets. Most frequent damages are scars (37 % of the microliths). Fractures (6 %) and MLIT (2 %) are scarcer (Table 7).

Five head or mesial bladelets of five projectiles were fractured. Four fractures are too short (length < 2 mm) or are cone initiating and are not specific to the impact. One fracture is diagnostic of the impact: a 3 mm long burination spin-off.

A head bladelet and an isolated bladelet of two projectiles that impacted the ground show MLIT that are parallel to the length of the blanks and extend from an impact fracture or a scar (Fig. 17). Such scarcity of experimental MLIT is to be expected in the archaeological record.

The head bladelet is the one receiving the strongest impact shock, but amongst the three hafted ranks of lateral inserts, they are quite surprisingly as often scarred as tail bladelets (Table 8). We distinguished four categories of scars on 25 lithic inserts, mostly isolated inserts (Fig. 18). The first one gathers large isolated scars, oblique to the edge, they can be quite large and invasive and are grazing. They have varied morphologies and terminations. The second and third groups gather scars that are overlapped or aligned and may show crushing. They have varied morphologies and terminations and are generally large. Differences between the second and third categories are their inclination and orientation: scars from the second group are oblique and grazing and those from the third group are slightly oblique or perpendicular to the edge and generally semi-abrupt. The fourth category brings together crescent break scars with a snap section and a half-moon morphology; they are found isolated or aligned.

6. Identifying projectile inserts and weapons designs

6.1. Lithic inserts impact fracture pattern

The low-frequency of lateral inserts fracturing at impact is coherent with previous experimental tests (Moss and Newcomer, 1982; O'Farrell, 1996; Pétillon *et al.*, 2011; Chesnaux, 2014). This low frequency is explained by several elements: lateral inserts can disperse rather than break at impact or extraction of the projectile. In some cases, the dispersion was imputed to the bad reaction of the hafting glue to impact, which broke rather than absorbed the impact shock (Pétillon *et al.*, 2011; Chesnaux, 2014). In our test, no bladelet got ejected owing to the fact that the glue got deformed and absorbed well the shock.

Beyond these contextual causes, experimental models developed by L. Chesnaux (2014) indicate that low fracturing rates are a common feature on lateral inserts, and contrast with the high-rates of DIF on axial and disto-lateral inserts.

At this point, it is not possible to differentiate fracturing patterns of lateral inserts according to 1/the projectile head designs tested here and 2/the propulsion modalities of projectiles that were shot with a bow (Chesnaux, 2014) or a spear-thrower (this experimentation and Pétillon *et al.*, 2011) despite the contrasting behaviours of projectiles.

6.2. Diagnostic LIS?

Categories of diagnostic LIS can be isolated based on the observation of damages of bladelets after their manufacture, trampling and use as projectile inserts (Table 9, Fig. 18):

- The category n°1 of scars related to the projectile use are specific to impact when exceeding 1 mm long. This size limit is due to morphological similarities with the category n°2 of trampling scars: both are bending initiated, isolated, relatively grazing, and oriented obliquely in reference to the edge. The length of trampling scars does not exceed 1 mm whereas impact scars are often longer, reaching 2,5 mm.
- The category n°2 of scars related to the projectile use are specific to impact. They are the most frequent on used flint inserts, being present on half of the scarred bladelets. They are grazing with a shallow to very deep bending initiation, overlapped, generally oblique to the edge, occasionally associated to edge crushing, and have varied morphologies and terminations. As a precaution, we propose to consider them diagnostic when exceeding 1 mm long since this experimentation may not illustrate all the variability of scars.
- The category n°3 of impact scars differs from the category n°2 by the inclination and orientation of scars, as they are semi-abrupt or abrupt and perpendicular or slightly oblique to the edge. The category n°3 of scars shares similarities with some retouch scars and the category n°1 of manufacturing scars, which is the reason why we could hardly consider them specific of impact. A size limit would not make sense here as the largest scars of this category are 1,5 mm long.
- The category n°4 of impact scars is observed in any situation (i.e. production, trampling and use) and is not to be considered diagnostic of any damaging cause.

6.3. LIS formation

Experimental results indicate distinctive damage features related to different modalities of forces application. Inclination, orientation and size are fundamental criteria for the LIS identification, as both LIS categories are grazing, generally oblique and large. The reason for it is the mechanism of force application causing their formation (Fig. 19): at impact and during the penetration, bladelets are submitted to several violent forces which are mainly parallel and oblique to their length of projectiles; extraction of the projectile generates similar forces in different intensities. Bending initiations appear to be a common criterion to both part of the DIF and the LIS.

Contrary to LIS, the scars that are caused by pressured retouch and trampling generally develop perpendicularly to the lateral edge of bladelets and are most often cone initiated (Fig. 19).

6.4. Distinct combinations of damages

The confrontation of combinations of damages between experimental sets shows that fractures are not systematically a distinctive criterion to identify impact (Table 10): transverse fractures with or without spin-offs whose length is inferior or exceeds 2 mm long occur during the manufacture, trampling, and use of bladelets as lateral inserts. The 2 mm length limit used to identify DIF is to be managed with care, always considering the chronology with the retouch and the recurrence of damages on the archaeological lithic assemblage. On the reverse, burination fractures are absent from the three experimental sets. These results notably contrast with those of L. Chesnaux (2014): in her tests, burination fractures were the most common fracture type on lateral inserts and no transverse fracture > 1,8 mm long developed after trampling or retouch.

In the present experimentation, the elements specific to impact are those less often considered in the functional analysis of microliths, namely LIS and MLIT. This underlines the importance of damages combination to interpret the function of stone tools. Although MLIT are difficult to exploit because of their scarcity, they are of great value to infer the orientation of forces causing damages. LIS being the most frequent stigmata, they have a particular value for the functional interpretation. Location and orientation of scars are expected to vary according to the position of microliths on projectiles and the subsequent orientation of forces; in that respect, they can participate in identifying hafting modalities. In our test as well as in the tests of L. Chesnaux (2014) and G. Pignat and H. Plisson (2000), LIS are the most frequent damages on lateral lithic inserts, whereas DIF are scarce. These results contrast with damaging pattern of axial or disto-lateral inserts, where DIF are relatively few to very frequent and LIS are scarce (Chesnaux, 2014). We argue that LIS rates, orientation, and location can participate in identifying the position of projectile inserts, along with fracture rates and types and MLIT orientation.

7. Confrontation to the archaeological record

Comparison of damages of EMM backed bladelets with experimental data shows that in both sites the sampled backed bladelets were only used as projectile inserts (Table 11, Table 12, Fig. 20).

7.1. DIF

Bladelets are almost systematically fractured at either one or both extremities (i.e. 97 % at La Marche and 99 % at the Blanchard cave, Table 13). Although the absence of impact points does not allow to ascertain it, the nearly systematic fracturing cutting through lateral backs suggests intentional breakage of blanks after retouch. It may have aimed at standardising length and rectifying the profile of tools.

Snap fractures are by far the most common fracture type, with 58 % at La Marche and 55 % at the Blanchard cave. DIF rates are high in both sites, with 34 % at La Marche and 51 % at the Blanchard cave (Table 13). They are often traumatic, with about half of them exceeding 4 mm long (i.e. 47 % at la Marche and 53 % at the Blanchard cave). DIF are generally parallel to the technological length of microliths, as when lithic inserts are placed axially or laterally.

The identified DIF types include burination, bending and spin-off fractures > 2 mm long. Rates of DIF types are different between sites: at La Marche, bending fractures are the most frequent (62 %), followed by burination fractures (30 %) and spin-off fractures (8 %). On the reverse, spin-off fractures are by far the most common DIF type at the Blanchard cave (40 %), regardless of the layer considered. They are followed by bending (27 %) and burination fractures

(13 %). Differences suggest a distinct application of forces at impact, possibly due to the variation of projectiles morphologies and lithic inserts positions.

7.2. MLIT

As observed on the experimental material, MLIT are the scarcest damage type. In most cases interpretation of striations is delicate because of post-depositional alteration processes such as mechanical friction which generated rounding of the prominences associated with rough polish, bright spots and striations with variable morphology and orientation. At La Marche, three groups of additive striations which are parallel to the technological length of the pieces extend from impact damages and may correspond to MLIT. At the Blanchard cave, one group of deep striations with a rough bottom extending from a short facial spin-off on snap fracture is attributed to impact; it is parallel to the technological length of a well-preserved backed bladelet. Orientation indicates that forces were exerted in a parallel orientation to the blank, as in lateral and axial positions.

7.3. LIS

LIS are frequent in both sites (i.e. circa 30 %) and are frequently the only damage allowing access to the function of microliths. In several cases, the cause of scarring is undetermined, either because scars morphology is not yet recognised experimentally, or is close to manufacturing and trampling, or is recut by alteration scars and is not visible. Scars on most bladelets were not attributed to impact as they are too small (< 1 mm) or similar to manufacturing and trampling scars. In these cases, they are generally abrupt, perpendicular to the edge and cone initiated.

Archaeological LIS can be particularly traumatic, relatively often exceeding 3 mm and exceptionally reaching 10 mm long. They are grazing, bending initiated, oblique to the lateral edge, occasionally associated with crushing and found either isolated, or more often overlapped. Their morphology and termination are variable, as observed in the experimental record (see part 6.2). Initiation depth is variable; when deep, scars can resemble the intentional notches of the denticulate backed bladelets. LIS do not show a preferential location and are developed on the whole length of several unretouched edges. These elements indicate that the tools hafted zone was probably the whole back.

LIS rates suggest that marginal double backing at the Blanchard cave aimed at reinforcing the fragile tearing/slashing edge. Double backed bladelets are indeed almost half less scarred by impact (26 %) than single backed bladelets (43 %).

7.4. Residues

Part of the bladelets from La Marche (38 %) and the Blanchard cave (3 %) present red, brown-orange or yellowish residues containing iron oxide. Eleven bladelets from La Marche present relatively important quantities of red or brown-orange residues concentrated on the back, and can be associated with impact damages. They may therefore correspond to hafting adhesive residues. Their preferential location near or on the abrupt back of the bladelets supports the functioning of backed bladelets as lateral inserts (Fig. 21, Gauvrit Roux 2019).

Hafting residues on Late Upper Palaeolithic backed bladelets are rarely documented. We point out that the residues on about 20 backed bladelets from the Lascaux cave are also specifically located on or near the back, and are associated with impact damages. They are

interpreted as hafting residues and their location indicates use as lateral inserts, as observed at La Marche (Allain, 1979; Allain and Rigaud, 1989).

7.5. Functional synthesis

To summarise, the orientation of damages suggests that bladelets were hafted laterally or axially and location of LIS and residues tend to indicate lateral position. It is not excluded that microliths were hafted in different manners but no element allows discriminating them. In particular, fracturing and scarring rates and lengths cannot be considered here because of preferential sampling of impact damaged pieces and possible intentional fracturing of blanks by the Magdalenians; new samplings are needed to precise functional interpretations.

The rectangular morphology of most EMM backed bladelets offers a longitudinal tearing/slashing edge with no point and would be best suitable for lateral hafting. Morpho-potential inferences are a relevant criterion only if they are linked to use-wears and in a systemic approach of archaeological assemblages. Experimental tests (Pétillon *et al.* 2011 and this experimentation) show that the morphology of backed bladelets is particularly well-adapted to be inserted in the grooves of osseous points. They may, besides, increase the depth of the projectile penetration in the target (Pétillon *et al.* 2011).

La Marche yielded over 119 Lussac-Angles points (Pinçon 1988) and the Blanchard cave 275 antler points (counts P. Paillet unpublished). Their grooves may have received flint inserts, as in the exemplar from the Blanchard cave (Allain and Descouts, 1957). The Lussac-Angles points and their lateral grooves are short and could only receive one bladelet laterally, according to the comparison of the mean lengths of the antler points lateral grooves and of the mean lengths of the backed bladelets from La Marche. On the contrary, the lateral grooves of the points from the Blanchard cave are longer and could receive several juxtaposed lateral bladelets, as would seem to attest the example of a point hafted with flint fragments all along a groove in this site (Fig. 1). The high rates of spin-off fractures on the bladelets from the Blanchard cave indicate that the origin of the main impact forces was parallel to the technological length of blanks; such high rates can occur at direct impact of an axial insert against the target, or, more likely here, when inserts juxtaposed laterally bang together at impact. The differences of DIF types proportions between sites could, therefore, be related to the number of backed bladelets that are inserted in the grooves and their juxtaposition or not.

8. Discussion

The unretouched lateral edges of bladelets are thin and fragile and can easily absorb a series of mechanical processes occurring from blanks production to the excavation of archaeological sites. This notably includes a range of taphonomical phenomena and the impact shock when tools were used as projectile inserts. The high frequencies of lateral scars on both experimental and archaeological microliths confer a particular value to this stigma for use-wear analysis.

Mechanical alterations are particularly varied and can cause a wide range of damages on lithic tools. For instance, trampling experimentations of lithic implements performed since nearly fifty years (e.g. Chesnaux 2014; Claud 2008; Flenniken and Haggarty 1979; McBrearty *et al.* 1998; Nielsen 1991; Prost 1988; Pryor 1988; Tringham *et al.* 1974) show that frequency and types of damages vary according to parameters such as blanks dimensions and edges angles, the type of raw material or the composition of the trampled sediment. Further experimentations are needed to investigate the variability of damages caused by mechanical alteration (e.g. soil movement and

compaction). Similarly, the methodological frame we developed for the LIS identification needs to be broadened in further tests. Indeed, numerous variables influence the formation of impact damages, such as the impacted materials, the penetration angle, the kinetic energy of the projectile (i.e. its mass and velocity), its diameter, the edge angle of the inserts and their raw material.

Scars are rarely taken into account in aid of DIF, but this work shows that their role in functional interpretations is fundamental because of their frequency, especially on archaeological backed pieces, and because they can participate in identifying hafting modalities of Palaeolithic microliths. Results underline the importance of damages association for the functional analysis of microliths.

This study shows that backed bladelets from La Marche and the Blanchard cave were specialised tools used as projectile inserts, and were probably placed laterally. Different elements need to be taken into account in the functional interpretation, including DIF rates, length, orientation and types, LIS rates, length, location and orientation, as well as MLIT orientation. Functional analysis shows that most of these criteria are similar or close between the studied sites. Only DIF types are fundamentally different. They suggest distinct projectile designs with potential variations of positions and/or number of lithic inserts that match the differences of the main morphologies of points in each site.

The EMM geographical diversity of antler points morphologies and bladelets functioning appears tightly linked to technical variations of the design and of the effectiveness of projectiles in the studied sites. Increasing the number of lithic inserts with a tearing/slashing role would indeed favour increasing the penetration depth of projectiles (Pétillon *et al.*, 2011). The EMM is marked by the diversification of osseous points morphologies and the inter-regional variations of the types of microliths (Langlais *et al.*, 2016; Pétillon, 2016; Sécher, 2020). This variability may induce a series of differences regarding the hafting arrangement of the antler point on the spear shaft (e.g. single- or double-bevelling), the equilibrium and weight of projectiles (e.g. the length of the antler point and the number of hafted lithic inserts), the fixation of microliths on the antler point (e.g. presence, size and morphology of grooves), the damages inflicted to the hunted prey (e.g. presence, position and number of hafted microliths). Put together, these elements may suggest the co-existence of projectiles with different mechanical properties at the EMM, and even potential variations of hunting techniques. Further experimentations are needed to better understand the implications of design changes on the effectiveness of projectiles.

The ethology and the size of hunted fauna, as well as an open or a wooded environment, can condition technical changes of approaching preys, of weight and morphology of projectiles, and of their propulsion modalities (Cattelain, 1994), and may participate in understanding the observed variations. However, according to the available data, hunted preys and environments appear similar in both sites: La Marche and the Blanchard cave were occupied during the cold and wet first phase of the Heinrich 1 event (Stanford *et al.*, 2011; Rasmussen *et al.*, 2014; Naughton *et al.*, 2016), which is characterised by open steppe landscapes (Allain *et al.*, 1985; Leroi-Gourhan, 1973), and in both sites the best represented taxa are horse and reindeer (Pradel, 1958; Bayle *et al.*, 2009). As a matter of fact, Middle Magdalenian hunts targeted large ungulates, and the distribution of these hunted ungulate species follows a regional pattern (Langlais *et al.*, 2012; Costamagno *et al.*, 2016) which is not related to the distribution of either specific osseous points or microliths. The widespread Upper Palaeolithic technology of composite projectiles appears indeed adapted to multiple environments varying in terms of climate, geography, vegetation

cover, or game (Pétillon *et al.* 2011). Variations expressed in the hunting equipment may therefore surpass mechanical and environmental constraints.

The hunting technical sphere is particularly important in societies of hunter-gatherers. The large number of flint bladelets and osseous projectile points in EMM sites underline its essential role. Hunting is, with trapping and fishing, one of the main ways to acquire vital animal resources for feeding (e.g. meat, marrow, fat). It also serves numerous technical spheres, notably linked to the processing of hides which may have been used for clothing, to using of tendons to make ties, or to working of osseous materials notably used to manufacture part of the domestic tools and the portable art. It is a pivot technical sphere and any inter-group variation related to it may notably have a major symbolic role in terms of cultural identity. This leads us to hypothesise that the variations of the efficacious properties of composite projectiles (e.g. morphology, weight, number of lithic inserts) may have had the value of a sign that potentially participated in the inter-group variability in west-central France during the EMM (Lemonnier 1984, 1987; Lévi-Strauss, 1973). The absence or the presence of a given technical element in close societies sharing similar environments can indeed only result from a choice (Lemonnier, 1984).

The symbolic distinction between the Lussac-Angles Magdalenian and the Navettes Magdalenian from west-central France is emphasised by their art production whose style and raw materials are profoundly different (Bourdier, 2010; Bourdier *et al.*, 2017; Fuentes, 2013). The shared artistic themes and microliths typology however indicate that the symbolic distinction between these Magdalenians is not exclusive: the representation of human figures associated with the production of truncated backed bladelets and the absence of scalene bladelets contribute to the unity of the EMM in west-central France. These elements also attest of a regional specificity since they are not found to be associated elsewhere.

9. Conclusion

The hunting activity is one of the rare Upper Palaeolithic technical spheres for which it is possible to build a systemic reflection that directly links stone and osseous productions: their conjoined use as composite projectiles is evidenced through impact damages analysis of both lithic inserts and projectile points, experimentation of projectile use as well as exceptional remains of preserved antler points hafted with lithic inserts. Although this association may have not been systematic, one could think that the common technical purpose of microliths and projectile points could induce their co-evolution and corresponding distribution patterns. However, their morphology and/or production techniques show arrhythmic evolution and different regional distribution. At the EMM, truncated backed bladelets are thereby found both in sites with Lussac-Angles points and long double-bevelled ones. The functional analysis developed in this work allows evidencing variations of technical behaviours that were not, until then, perceived through the comparison of EMM production techniques and typology of microlith assemblages in west-central France but that match differences of projectile points morphology. This study underlines that the function of stone tools is an important field of cultural demarcation that plays a major role in understanding the transformation and variation of toolkits and techniques. Therefore, by jointly confronting the variations and transformations of morphology, production and use techniques of both lithic to osseous records, it is possible to access to a part of the complex Magdalenian hunting techniques and offer a rich insight into past cultural dynamics.

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Site	Sample location	Laboratory number	Age (radiocarbon years BP)	Standard error	Age in cal BP	Dated material	Reference
Blanchard cave	B6 sector HO	ETH-28492	15290	90	18758-18346	<i>Rangifer tarandus</i> , right tibia	Despriée <i>et al.</i> , 2009
Grand Abri	B2 sector F	ETH 29155	15080	100	18586-18041	<i>Equus species</i> , long bone	Despriée <i>et al.</i> , 2009
Grand Abri	B unknown sector	ETH-29156	15070	100	18575-18030	<i>Equus species</i> , long bone	Despriée <i>et al.</i> , 2009
Blanchard cave	B5 sector HO	ETH-28493	15050	90	18538-18021	Bovid, right tibia	Despriée <i>et al.</i> , 2009
Grand Abri	B2 sector G	ETH-29158	15020	100	18515-17975	<i>Equus species</i> , long bone	Despriée <i>et al.</i> , 2009
Blanchard cave	B4 sector HO	ETH-28494	15010	90	17450-16752	<i>Equus species</i> , left tibia	Despriée <i>et al.</i> 2009
Grand Abri	B1 sector F	ETH-19154	14980	100	18465-17940	<i>Equus species</i> , long bone	Despriée <i>et al.</i> , 2009
La Marche	–	Beta-359091	14870	50	18263-17905	<i>Equus species</i> , tooth	Brou <i>et al.</i> , unpublished
Grand Abri	B sector E	ETH-29157	14840	100	18331-17810	<i>Equus species</i> , long bone	Despriée <i>et al.</i> , 2009
La Marche	–	Beta-359090	14740	50	18105-17752	<i>Equus species</i> , tooth	Brou <i>et al.</i> , unpublished
La Marche	–	Oxa-30980	14685	75	18077-17646	Human tooth	Barshay Szmidt <i>et al.</i> , 2016
La Marche	–	Beta-359089	14560	60	17939-17552	<i>Equus species</i> , tooth	Brou <i>et al.</i> , unpublished
La Marche	–	Ly 2100	14280	160	17853-16945	Bone	Pradel, 1980
Grand Abri	B2	Ly-3000	14270	270	18031-16571	Microfauna	Despriée <i>et al.</i> , 2009
Grand Abri	B2 square E8	ETH-26103	14070	100	17450-16752	<i>Rangifer tarandus</i> , antler	Despriée <i>et al.</i> , 2009
Blanchard cave	B5	Ly-1127	14080	350	17994-16149	Bone	Radiocarbon V. 20, p. 49
La Marche	–	Beta-359088*	12580	50	15174-14652	<i>Equus species</i> , tooth	Brou <i>et al.</i> , unpublished

Table 1. Radiocarbon dates of the two studied sites, and of the Grand Abri whose stratigraphy is correlated to the Blanchard cave. *aberrant age that does not correspond to the EMM occupation. Standard deviations > 400 years excluded. Ages calibrated with OxCal v4.3.2 (Bronk Ramsey, 2017), IntCal13 atmospheric curve (Reimer *et al.*, 2013).

	Projectile head design				Total
	1	2	3	4	
Number of antler points	3	3	3	15	24
Number of bladelet per groove	3	3	3	1	–
Number of hafted bladelets	18	18	18	30	84

Table 2. Number of antler points, bladelets per groove and hafted bladelets according to the four projectile head designs tested.

	Archaeological points						Experimental points					
	The Blanchard cave grooved points			La Marche Lussac-Angles points			Designs 1, 2, 3			Design 4		
	Length	Width	Thickness	Length	Width	Thickness	Length	Width	Thickness	Length	Width	Thickness
Average	161,5*	10,5	9	77,9	11,5	8,5	150,9	11,7	10,7	80,5	13	9,9
Standard deviation	–	–	–	–	–	–	21,2	1,2	1,6	6,8	2	1,2
Maximum	324*	17,5	13	129	14	11,2	184	13	13	91,5	16	12
Minimum	74,5*	6	6	44,5	9,1	6,1	118	10	8	70,5	9	8,5

Table 3. Dimensions of the archaeological and experimental points in mm. Data from Houmard, 2003 for 159 points from the Blanchard cave and the Grand Abri at La Garenne. Data from Pinçon, 1988 for 119 Lussac-Angles points for La Marche. *Length of whole or almost whole points (N = 16/159).

Manufacturing damages	Total	%
Fracture	107	59,1
Fracture + scars	16	8,8
Fracture + micro-wears	8	4,4
Fracture + scars + micro-wears	1	0,6
Scars + micro-wears	3	1,7
Scars	8	4,4
Micro-wears	4	2,2
Intact	34	18,8
Total	181	100

Table 4. Damages due to manufacturing of backed bladelets.

Trampling damages	Bladelets covered by 2 cm of sediment	Surface bladelets	Total	%
Fracture	–	1	1	2,2
Fracture + scars	1	3	4	8,9
Fracture + scars + micro-wears	–	4	4	8,9
Scars + micro-wears	1	2	3	6,7
Scars	9	–	9	20
Intact	23	–	23	51,1
Lost	1	–	1	2,2
Total	35	10	45	100

Table 5. Damages due to trampling of backed bladelets according to their position during the experimentation.

Antler points damages	Fracture length (mm)					Total
	0	<1	1	1,5	6	
Crushing	5	–	–	–	–	5

Crushing + hinge terminated bevel fracture	–	–	1	–	–	1
Crushing + step terminated bevel fracture	–	1	–	–	–	1
Feather terminated bevel fracture	–	–	2	2	–	4
Embryonic bevel fracture	–	–	–	–	1	1
Intact	12	–	–	–	–	12
Total	17	1	3	2	1	24

Table 6. Damages of the tip of the antler projectile points after the shooting experimentation.

Impact damages	Projectile design				Total	%
	1	2	3	4		
Fracture + scars	–	2	–	2	4	4,8
Fracture + micro-wears	–	–	1	–	1	1,2
Scars + micro-wears	–	–	–	1	1	1,2
Scars	5	5	5	10	25	29,8
Intact	12	11	12	16	51	60,7
Lost	1	–	–	1	2	2,4
Total	18	18	18	30	84	100

Table 7. Damages due to use of backed bladelets as projectile inserts according to the head designs tested.

Bladelet position	Nb hafted bladelets*	Nb scarred bladelets	% scarred bladelets
Isolated armature	29	13	44,8
Head	18	5	27,8
Mesial	18	7	38,9
Tail	18	5	27,8
Total	82	30	36,6

Table 8. Scarring of the lateral inserts according to their location on the antler points. *number of recovered bladelets.

		Use as projectile insert				Manufacture			Trampling			
		categ. 1	categ. 2	categ. 3	categ. 4	categ. 1	categ. 2	categ. 3	categ. 1	categ. 2	categ. 3	categ. 4
Initiation type	cone						×		×		×	
	bending	×	×	×		×				×		
	snap				×			×				×
Initiation depth	shallow	×	×	×	×	×	×	×	×	×	×	×
	deep	×	×	×	×			×	×		×	×
Inclination	grazing	×	×							×		
	semi-abrupt			×		×	×		×	×	×	
	abrupt			×	×	×	×	×	×		×	×
Disposition	isolated	×			×		×	×	×	×		×
	aligned				×	×		×			×	×
	overlapped		×	×							×	
Crushing	present		×	×							×	
	absent	×	×	×	×	×	×	×	×	×		×
Orientation	undetermined				×			×				×

	perpendicular			×		×	×		×		×	
	slightly oblique			×		×	×		×		×	
	oblique	×	×							×		
Morphology	half-moon				×			×				×
	semi-circular	×	×	×		×	×		×	×	×	
	triangular		×			×				×	×	
	trapezoidal	×	×			×					×	
	quadrangular	×	×	×								
	irregular		×									
Termination	feathered	×	×	×		×			×		×	
	hinge	×	×	×		×	×		×	×	×	
	step	×	×	×						×	×	
	snap				×			×				×
Length (mm)		≤ 2.5	≤ 3	≤ 1.5	–	≤ 1	≤ 1	–	≤ 1	≤ 1	≤ 2	–

Table 9. Comparison of the characteristics of the categories of scars identified in the three experimentations. Crosses indicate presence.

	Manufacture	Trampling	Use as projectile insert
Undetermined fracture morphology	1%*	0%	0%
Transverse fracture with/without spin-offs (< 2 mm)	66%*	18%	4%
Transverse fracture with/without spin-offs (> 2 mm)	8%	2%	2%
Burination fracture (> 2 mm)	0%	0%	0%
Grazing, oblique, bending initiated lateral scars (> 1 mm)	0%	0%	28%
Striation/polish (sub)parallel to the length of bladelets + extending from fracture or lateral scars	0%	0%	2%

Table 10. Comparison of the combinations of damages in the three experimental sets. Percentages express number of pieces. *including non-quantified intentional fractures.

Fracture	Lateral edge scarring			Total	%
	Diagnostic	Undetermined	Not scarred or not diagnostic		
Proximal diagnostic	11	1	21	33	19,1
Distal diagnostic	9	2	31	42	24,3
Proximal + distal diagnostic	3	–	11	14	8,1
Not fractured or not diagnostic	37	4	43	84	48,6
Total	60	7	106	173	100
%	34,7	4,0	61,3	100	

Table 11. Fractures and laterals scars on the backed bladelets from the Blanchard cave.

Fracture	Lateral edge scarring			Total	%
	Diagnostic	Undetermined	Not scarred or not diagnostic		
Proximal diagnostic	11	–	20	31	16,9
Distal diagnostic	5	3	19	27	14,8
Proximal + distal diagnostic	1	–	3	4	2,2
Not fractured or not diagnostic	42	16	63	121	66,1
Total	59	19	105	183	100
%	32,2	10,4	57,4	100	

Table 12. Fractures and laterals scars on the backed bladelets from La Marche.

Type of microlith	The Blanchard cave			La Marche		
	Nb analysed	Nb fractured	Nb with DIF	Nb analysed	Nb fractured	Nb with DIF
Appointed and truncated simple backed bladelet	–	–	–	1	1	1
Appointed double backed bladelet	2	2	2	1	1	–
Appointed simple backed bladelet	–	–	–	1	1	–
Bitruncated simple backed bladelet	–	–	–	2	1	1
Denticulated simple backed bladelet	2	2	2	–	–	–
Double backed bladelet	57	56	30	4	4	1
Microperforator on simple backed bladelet	–	–	–	1	1	–
Microperforator on truncated bladelet	–	–	–	1	–	–
Notched simple backed bladelet	–	–	–	1	–	–
Simple backed bladelet	60	60	30	133	133	47
Truncated double backed bladelet	24	24	11	1	1	–
Truncated simple backed bladelet	28	28	13	37	34	12
Total	173	172	88	183	177	62

Table 13. Fracturing per type of microlith.

Fig. 1. Magdalenian projectile points hafted with microliths. 1: Antler point with flint fragments in a groove from the Blanchard cave, n°999-10-483, after Rigaud, 2009. 2: Details of the flint splinters in the groove of 1, picture A. Rigaud. 3: Antler point hafted with flint bladelets, Pincevent, n° IV2 27-M 89.378, modified after Valentin, 2008.

Fig. 2. Sites location. Base-map Esri, USGS, NOAA.

Fig. 3. Model of radiocarbon ages of the EMM occupations of the Blanchard cave and La Marche. The ¹⁴C ages used are detailed in Table 1; aberrant age excluded (Beta-359088). Stratigraphic constraints imposed for the Blanchard cave (layers B6>B5>B4). Confidence bar: 95 %. Chronomodel 2.0.18. Intcal13 atmospheric curve (Reimer *et al.*, 2013).

Fig. 4. Examples of EMM projectile points. 1: Short single-bevelled lanceolate Lussac-Angles point from La Marche, excavations J. Airvaux, picture by J. Airvaux. 2: Long double-bevelled point with quadrangular section from the Roc-de-Marcamps, Maziaud collection, picture by J.-M. Pétilion.

Fig. 5. Examples of microliths from La Marche and the Blanchard cave. 1: Bitruncated backed bladelet from La Marche. 2: Truncated backed bladelet from La Marche. 3-4: Mesial fragments of backed bladelets from the Blanchard cave.

Fig. 6. Categories of fractures distinguished.

Fig. 7. Elements of description of scars. 1: Terminology of description, modified after Claud, 2008. 2: Main orientations of scars, modified after Prost, 1993. 3: Disposition of scars, after Ibáñez Estévez and González Urquijo, 1994.

Fig. 8. Projectile head designs tested. 1: Three ranks of joined lateral inserts forming a continuous slashing edge; the unretouched lateral edges are sub-parallel to the projectile. 2: Three ranks of disjointed lateral inserts forming a discontinuous slashing edge; the unretouched lateral edges are slightly oblique to the projectile. 3: Three ranks of joined lateral inserts forming a continuous slashing edge; the unretouched lateral edges are slightly oblique to the projectile. 4: One single lateral insert hafted per groove; the unretouched slashing edge is sub-parallel to the projectile.

- Fig. 9.** Morphometric comparison of the EMM points. 1: Average sizes and morphological tendencies of the Lussac-Angles points from la Marche, after the data from Pinçon, 1988. 2: Average sizes and morphological tendencies of the Blanchard cave points, after the data from Houmard, 2003a.
- Fig. 10.** Examples of experimental projectile heads. Left: fourth head design. Right: second head design.
- Fig. 11.** Spear-throwers (type 2a) from La Garenne. 1: The Blanchard cave, n°999-10-1292/SM-L1-B5. 2: Undetermined cave on La Garenne hillside, n°999-10-1335/SM-CLA 78 and HIII-B1-140- EZ-10. After Cattelain, 2017.
- Fig. 12.** Three categories of lateral scars due manufacturing of backed bladelets. 1: First category of manufacturing scars. 2: Second category of manufacturing scars. 3: Third category of manufacturing scars.
- Fig. 13.** Four categories of lateral scars due to trampling of backed bladelets. 1: First category of trampling scars. 2: Second category of trampling scars. 3: Third category of trampling scars. 4: Fourth category of trampling scars.
- Fig. 14.** Behaviour during the flight of a projectile shot with spear-thrower. Pictures by E. Antolinos-Basso and E. Gauvrit Roux.
- Fig. 15.** A projectile from shooting to damages analysis (head design n°2). 1: Trajectory and deformation of the projectile. 2: Same projectile after impact; only case where the hafting broke after the penetration. 3: Fracture and cracking of the cranium due to the projectile penetration. 4: The projectile head after impact; one bladelet fragment remained in the target after extracting the projectile. 5: Slight deformation of the point. 6: Fracturing of a mesial bladelet. Pictures by E. Antolinos-Basso, E. Gauvrit Roux, C. Zen.
- Fig. 16.** Antler points damages. 1: Crushing. 2: Crushing and short stepped terminated fracture. 3: Feather terminated fracture. 4: Bevelled embryonic fracture.
- Fig. 17.** 1: Lower face of an impacted backed bladelet before cleaning; the arrows indicate the orientation of the damages. 2: Detail of linear impact traces before cleaning. 3: Long additive striations due to impact observed after cleaning with warm water and soap and then alcohol.
- Fig. 18.** Four categories of lateral scars due to use of backed bladelets as projectile armatures. 1: First category of impact scars. 2: Second category of impact scars. 3: Third category of impact scars. 4: Fourth category of impact scars.
- Fig. 19.** Different forces in action. 1: Main forces at impact and during projectile penetration in a target, adapted after models developed for needle insertion (Fukushima and Naemura, 2014) and modern projectile heads (Syngellakis, 2017). 2: Main forces generating lateral scars in examples of pressure retouch and trampling. 3: Example of invasive grazing oblique scars developed after impact. 4: Example of short abrupt scars perpendicular to the edge developed after pressure retouch or trampling.
- Fig. 20.** Impacted backed bladelets from the Blanchard cave (1-4) and La Marche (5-8). 1: Large overlapped grazing and oblique scars with bending initiation associated with edge crushing. 2: Large grazing and oblique scars cutting through direct marginal retouch and edge rubbing. 3: Linear impact traces extending from short facial spin-offs developed on a snap fracture. 4: Large facial spin-offs developed from a snap fracture. 5: Large overlapped grazing and oblique scars with bending initiation. 6: Large grazing and oblique scar. 7: Large grazing and oblique scar. 8: Burination fracture.
- Fig. 21.** Example of residues on a backed bladelet. 1: Backed bladelet from La Marche covered with red residues. 2-3: MEB EDS analysis of the homogeneous residues mostly composed of iron oxide; the

white cross indicates the location of the analysed point. 4-5: Back of the bladelet where most of the residues are located.