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Experimental Replication and Use of Cantabrian Lower Magdalenian Antler Projectile Points

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While researchers have long analysed the artistic and typological aspects of Magdalenian antler implements, relatively little effort has been expended upon learning their functional aspects. In order to understand better the applications of antler as a raw material as well as the durability and potential use life of projectile points made from it, the author hafted and threw 20 replicated Cantabrian Lower Magdalenian spearpoints at a dead animal target until breakage was induced. The results indicate the high durability of antler projectile points and their long use life, far beyond what can be expected from a stone point used in similar contexts. The choice of antler over stone in Cantabrian Lower Magdalenian hunting contexts fits within the overall hunting strategy of reliably engineered technology used to acquire large game herds in mass harvests.

Keywords: SPAIN, CANTABRIA, LOWER MAGDALENIAN, PROJECTILES, ANTLER, EXPERIMENTAL ARCHAEOLOGY.

Introduction

The Lower Magdalenian period in Cantabrian Spain encompasses a time of increasing intensification of the ‘‘wild harvest’’ of food resources (Freeman, 1973, 1975). These include the harvest of entire herds of red deer (Straus, 1977, 1987*a*; Klein *et al*., 1981; Klein & Cruz Uribe, 1987) and ibex (González Echegaray & Barandiarán, 1981; Straus, 1987*b*), and the increased harvest of marine molluscs (Straus, 1986; Krupa, 1994) and salmon (Krupa, 1996; Pokines & Krupa, 1997). The projectile technology spanning this period also changed, from the predominantly lithic (with some antler) points of the Solutrean period (Straus, 1990) to the antler projectile points typical of the Cantabrian Lower Magdalenian (González Echegaray, 1960; Utrilla Miranda, 1981). These are predominantly rectangular in profile and have bevelled bases, presumably for hafting (Pokines, 1993), though other forms appear (Pokines & Krupa, 1997). Projectile armatures changed after this period, with the appearance of multiple-barbed antler harpoon heads marking (by definition) the Cantabrian Upper Magdalenian period. These Cantabrian Lower Magdalenian projectile points played an important role in the hunting strategy of the time, given their frequent appearance in sites and the importance of large terrestrial mammal species among recovered food remains.

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In order to ascertain the effectiveness of Cantabrian Lower Magdalenian antler projectile points as hunting implements in comparison to lithic points, I performed an experiment involving the replication, hafting and throwing at an animal target of 20 such points. These were copied from the numerous examples excavated to date from sites in the region, such as El Juyo (Barandiarán, 1987; Pokines, 1993), Rascaño (Barandiarán, 1981), and La Riera (González Morales, 1986). The object of this experiment was not to replicate the actual manufacturing and hafting process, but to test the effectiveness and durability of antler as a material for projectile points. In addition, the physical parameters of manufacture, usage, use life, damage and repair of antler points must be wholly different from those of flint points, whose typical role (in other archaeologically known hunter-gather artefact complexes) was filled by antler points in Cantabrian Lower Magdalenian tool kits.

The reaction of flint points to the stresses incurred in hunting situations has been studied through replication and hafting experiments (Bergman & Newcomer, 1983; Flenniken, 1985; Flenniken & Raymond, 1986; Odell & Cowan, 1986; Titmus & Woods, 1986; Frison, 1989; Chadelle, Geneste & Plisson, 1991; Morel, 1991, 1993; Broglio, Chelidonio & Longo, 1993; Cattelain & Perpère, 1993; Geneste & Plisson, 1993; Shea, 1993; Callahan, 1994; Geneste & Maury, 1997), as have their antler counterparts (Tyzzer, 1936; Newcomer, 1974; Guthrie, 1983; Arndt & Newcomer, 1986; Bergman, 1987; Knecht, 1991*a*, 1991*b*, 1993, 1997; Pokines, 1993;

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Pokines & Krupa, 1997). These latter studies, however, generally do not attempt to quantify use life of experimental points. Reports concerning the use of antler projectile points among historically and ethnographically known cultures (Curtis, 1911; Townsend, 1981; MacGregor, 1985) lack the detail necessary to evaluate the functional performance of these implements. Thus, an experiment was designed to determine the reactions of antler projectile points to the likely stresses they would encounter when used to hunt large terrestrial mammals.

Methods

The antler obtained for this purpose came from the herd of North American elk living in the National Elk Refuge of Jackson, Wyoming. All the antler used for the replicated points came from recent kills (no shed antler was used). North American elk, while often designated as a subspecies or geographic race differing from European red deer, belong to the same species (*Cervus elaphus*) (Clutton-Brock, Guiness & Alban, 1982). The two groups are interfertile and produce fertile offspring of intermediate characteristics (Bryant & Maser, 1982: 12). The physical qualities of elk antler are therefore assumed not to differ significantly from those of the red deer antler used by Magdalenian hunters.

Segments of antler were cut with an ordinary handsaw to the approximate lengths of finished spear points. Each segment was then soaked in water for 2 to 3 days prior to further processing in order to soften the material. Following the recommendation of MacGregor (1985: 64), temporary additional softening was obtained by placing the antler segments in heated water. Pieces were then cut longitudinally into point blanks with a hacksaw. Cutting continued until the segment began to cool and reharden, making cutting more difficult. A cooled segment was then alternated with one that had been kept in heated water. In this manner, individual pieces were immersed in heated water for a total of 3 to 4 h during the cutting process. These antler blanks were then sanded into final shape using an ordinary power sander at moderate speed setting.

The finished spear points were given a uniform 5 cm single basal bevel for hafting (Figure 1), although other individual dimensions vary somewhat (see Table 1). Finished points range from 131 mm to 157 mm in length, 10 mm to 12 mm in maximum width and 7 mm to 10 mm in maximum thickness, placing them towards the upper end of the size range for points recovered from El Juyo. Since most smaller fragments came from point portions where the maximal dimensions were not present, the larger size is accepted as more representative. Profile shape varies from quadrangular forms (18 of 20 points) to oval (2 of 20). The shape, size and curvature of the antler blanks influenced the finished form of each point, given that each blank was shaped into the largest spear point possible. It should be noted that the easiest (hence, the most plentiful) profile form to shape from blanks cut in this manner is quadrangular, since this was the basic shape of the blanks themselves.

Figure 1. Close-up of the bevel end of two replicated points, No 10 and No 14. Note the interior, porous texture at the top of each that is a remnant of the interior spongy portion of antler. Scale is in cm.

Each bevel surface was scored repeatedly prior to hafting to enhance adherence of the mastic. A modular system of hafting was chosen, where each point was attached to its own foreshaft. Each foreshaft was then plugged into the hole at one end of a larger spear shaft, thus obviating the need for many large spears and allowing for the identical delivery implement to be used with each point. Foreshafts were made from 15 cm segments of hardwood dowel 11 mm in diameter, bevelled to accommodate the bases of the antler spear points. Hafting was accomplished using carpenters glue, followed by the wrapping of the joint with cotton twine held secure by more glue. Final hafted lengths ranged from 237 mm to 263 mm (Table 1). Natural materials such as sinew and pine pitch were not utilized since neither was readily available. The author assumes the Magdalenian hunters were expert in their ability to secure their spear points to a shaft, since their survival

Table 1. Replicated point dimensions

Point No	Maximum (mm) L	W	Th	Profile shape	Hafted length
1	146	11	7	QUAD.	251
2	144	11	8	OVAL	245
3	134	11	9	OVAL	237
4	131	11	9	QUAD.	236
5	131	11	9	QUAD.	237
6	141	11	9	QUAD.	243
7	135	11	8	QUAD.	240
8	144	10	9	QUAD.	249
9	142	11	9	QUAD.	242
10	147	10	10	QUAD.	252
11	146	12	9	QUAD.	249
12	153	10	8	QUAD.	257
13	136	10	9	QUAD.	242
14	147	10	9	QUAD.	255
15	138	11	7	QUAD.	247
16	146	10	9	QUAD.	253
17	157	10	9	QUAD.	263
18	150	12	10	QUAD.	253
19	157	10	9	QUAD.	261
20	141	10	8	QUAD.	247

Note that since each foreshaft base fits into a 5 cm deep socket in the spear shaft, this amount is subtracted from the full hafted length of each spear point when calculating its full penetration depth.

depended upon such expertise in the manipulation of natural materials. In the experiment, the effects of their techniques were mimicked (secure hafting) rather than the particulars (the manner of hafting), since the latter is more based upon speculation. In the ensuing experiment, the utilized hafting technique proved adequate in holding points securely to their foreshafts through repeated throws, and it did not prevent full penetration of the foreshafts.

A round softwood shaft 31 mm in diameter and 2 m in length served as a hand-thrown spear for these experiments. One end was drilled with a 5 cm deep hole large enough to accommodate the foreshafts snugly. The outside surface of the spear on the projectile end was bound with twine in order to reduce the chance of splitting. This spear size was chosen according to the success of previous experimenters who utilized similar spears while working with flint projectile points (Flenniken, 1985; Odell & Cowan, 1986; Frison, 1989). A throwing range of 3 to 5 m was maintained throughout the experiment in order to minimize the number of misses.

The target throughout the experiment was one half (minus head and feet) of a dressed carcass of a commercially available domestic goat (*Capra hircus*). This half-carcass weighed 11 kg and came from an individual that had not undergone fusion of the majority of long bones. The estimated undressed weight was on the order of 30–35 kg. Knecht (1991*b*) utilized replicated Early Upper Paleolithic antler points propelled by a crossbow in her experiments with a natural target. Her results indicate that antler points can easily achieve full penetration, even through a whole goat carcass with hide still attached. Since ibex (*Capra ibex*) and chamois (*Rupicapra rupicapra*) are species that were often taken by Magdalenian hunters in Cantabrian Spain (Straus, 1977, 1987*a*, 1987*b*, 1991, 1992; Freeman, 1981; Clark & Straus, 1983), the use of domesticated goat as a target is an adequate substitute for red deer.

The target was placed on the ground and held upright (about 45° from the horizontal) against a low mound of loose, sandy soil. The spear was released after a striding start, between 3 and 5 m away from the target. The results of each throw were recorded immediately thereafter, with each point being used successively until significant damage had accrued.

Results

The results of this experiment are summarized in Table 2. Each throw was tabulated as a complete miss, a miss penetrating soil or a target hit. ''Complete misses'' are throws where the point struck nothing and the spear bounced parallel to the ground, thus having little potential for damage to the point. In one case only (Point No 1) was a spear point damaged as the result of a complete miss: the spear bounced off the ground after missing the target and struck stone laterally, causing the point to snap at the top of its foreshaft. ''Misses penetrating soil'' are throws that missed the goat target but struck fully into the ground. Here, the potential for damage exists if the point strikes a stone or other hard object, or through bending stress caused by the weight of the spear after penetration into the ground.

One spear point (Point No 2) was broken as a result of a (final) throw where the target was missed but the ground was struck at a sufficient angle to cause full penetration. In this case, the sound of the spear point striking a hard object could be heard clearly, which upon examination proved to be a piece of metal. It is possible that some of the other spear points passed completely through the target without receiving damage, only to break upon striking some object in the soil or through the lateral stress of the resting spear. Such an instance was not always possible to detect and may have been recorded as breakage upon impact with the target body itself. I believe that this scenario applies at least to spear point No 10, which penetrated a portion of the carcass lacking bone but was found broken against a stone in the ground. The category of each type of throw (complete miss, miss penetrating soil, or target hit) in which the point accrued significant damage and was retired from further experimentation is marked on Table 2 with an asterisk: 18 of the 20 points broke only upon impact with the target, the other two points having broken against hard objects in or on the ground.

A total of 249 throws were launched at the goat target. Of these, 51 were complete misses as described in the preceding paragraph. Of the remaining 198 throws, 48 impacted directly into the soil and 150 struck the target. The great majority of throws hitting

Table 2. Results of hafting and throwing experiment

Point No	Total throws	Complete misses	Misses penetrating soil	Target hits	Final damage
1	11	5*	1	5	2 mm off tip & break at top of foreshaft
2	9	1	4*	4	14 mm off tip
3	10	1	3	6*	4 mm off tip
4	4	0	1	3*	7 mm off tip
5	3	1	0	2*	4 mm off tip
6	6	1	1	4*	21 mm off tip
7	22	6	3	13*	8 mm off tip
8	7	0	2	5*	7 mm off tip
9	15	2	4	9*	25 mm off tip
10	24	4	5	15*	8 mm off tip
11	40	13	8	19*	8 mm off tip
12	4	0	1	3*	5 mm off tip
13	6	2	0	4*	7 mm off tip
14	13	1	4	8*	8 mm off tip
15	6	0	2	4*	16 mm off tip
16	16	4	2	10*	35 mm off tip
17	13	1	2	10*	27 mm off tip & break at top of foreshaft
18	18	4	1	13*	7 mm off tip
19	17	3	2	12*	5 mm off tip
20	5	2	2	1*	12 mm off tip
Total	249	51	48	150	

*Indicates the category of hit/miss of the throw in which the significant damage causing the use of the point to be terminated was accrued. Thus, only in the cases of the first two points was a point broken striking something other than the target.

the target also achieved some penetration into the ground underneath it. Each spear point lasted an average of 9·9 strikes into soil or the target. If one includes complete misses in this calculation, the average number of throws without inducing breakage is still greater. Since throws that resulted in complete misses showed extremely little potential for causing damage to the experimental points, they generally should be disregarded in calculations of point longevity. If one disregards throws that missed the target but still penetrated into soil in the calculation of antler point longevity, the average number of throws before breakage (number of target hits divided by the number of points) is 7·5.

The middle calculation (9·9) is considered the most valid indication of relative point longevity. One may surmise that the ground is the most likely object against which an antler point used in an actual hunting situation would impact should the desired animal target be missed. Numerous other non-replicable factors affect the longevity of spear points used in actual hunting situations. These factors include the possible use of spearthrower- or bow-propelled projectiles (Bergman, 1993; Cattelain, 1997). Use life, being a function of the durability of a point and the stresses to which it is subjected, is an adequate measure of durability among point types if the experimental stresses to which they are subjected are comparable.

The type of damage accrued by these antler points is also listed in Table 2. In two cases only was the damage induced during the experiment more substantial than the breakage of a small fraction off the tip. Only points No 1 and No 17 suffered severe damage: each snapped where the haft binding ends at the top of the foreshaft (Figure 2). Even these could have been refashioned into smaller points, which is known to happen among archaeologically recovered points (Barandiarán, 1987; Pokines, 1993). The remainder of points, except for No 16 which lost 35 mm off its tip, could have been resharpened quite easily and used again, some in a matter of minutes.

The penetrative ability and general toughness of these antler points are the most striking qualities made apparent by this experiment. Of the 150 throws that struck the target, 126 fully penetrated it, whereby the spear point and foreshaft were embedded to the top of the (31 mm diameter) spear shaft itself. Each of the remaining 24 target hits achieved significant partial penetration: the least penetration achieved was to the location midway between the spear point tip and the beginning of its basal bevel. This instance of most shallow penetration occurred when one spear point (No 7) struck and broke upon the pelvis of the target animal. In most instances the easiest way to remove an embedded spear was first to remove the foreshaft from the spear shaft and then push the point all the way through the carcass. While this option might not be available to a hunter dealing with a whole carcass, a similar hafting system would allow a spear shaft to be retrieved while its point and foreshaft remained embedded in an animal. The spear shaft could then be retrieved and fitted with a replacement point and foreshaft during the same hunting episode.

Figure 2. Replicated spear points No 11 to No 20 are shown after hafting and throwing. Note that No 17 (fourth from right) is broken at the top of its hafting string. All other damage is visible. Scale is 5 cm.

The performance of spear points impacting in the area of the rib cage is particularly significant. Out of 150 target hits, 54 struck within the area of the rib cage. Of these 54 hits, only 3 caused detectable damage to the point involved. Determination of the degree to which a point has struck a rib, glanced off it, or penetrated between two ribs without significant contact with either of them was difficult in practice, given the flexibility of the carcass and the degree to which the points tended to slide past ribs without stopping or breaking. If one assumes that the ribs and the intercostal spaces constitute roughly equal areas, any point arriving at random in the area of the rib cage has roughly equal chances of first coming into contact with bone or flesh. One would therefore expect about half of the 54 hits in the rib area to have contacted bone upon initial impact.

The damage to antler points from rib impacts, was, however, minimal. Points No 3, 4 and 8 were retired after striking a rib, losing only 4 mm, 7 mm and 7 mm respectively from their tips. All three points could have been resharpened with little effort and put back into use with no decrease in performance. Point No 7 struck the sixth rib directly, broke completely through it, and achieved full penetration through the carcass and into the soil beneath, all without being damaged. Similarly, Point No 11 broke the fifth rib and penetrated to the top of its haft binding, without suffering any damage to itself.

Full penetration into the rib cage was the norm: 43 of these 54 hits involved full penetration of the points through the carcass and into the underlying soil. If one assumes that lung tissue is less of an impediment to spear point penetration than is soil, the devastating character of these antler points becomes apparent. It is desirable for a projectile to strike the lungs of a large game animal, since such an injury will bring down an animal quickly, resulting in the loss of fewer wounded animals (Mohler & Toweill, 1982; Guthrie, 1983: 282). With the object of bringing down an animal quickly and efficiently, a hunter has a limited range of targets on an animal to choose from: the brain, spinal column, heart, lungs or major artery. The lungs are a preferred organ to aim at by hunters lacking modern firearms: lungs are less well protected and/or a larger target than the other choices available.

Further examples of the devastating effects these antler spear points had upon the goat target are illustrated in Figures 3 and 4 (which are very similar to the damage detected by Noe-Nygaard (1974) resulting from Mesolithic hunting in Denmark). Figure 3 shows the (right) scapula with four holes punched completely through it by spear point impacts. Point No 1 sustained no significant damage in creating the hole in the superior margin of the scapula pictured and was not retired after the throw when this hit occurred. Points No 5, No 9 and No 11 created the remaining three holes in the scapula. These three points suffered (respectively) the loss of 4 mm, 25 mm and 8 mm off their tips. Each point was retired after impacting with the scapula, but each could have been returned to service with little or no resharpening. Figure 4 shows the (right, unfused) humerus. Embedded in the proximal end is a 3 cm long segment of the tip of one spear point (No 16) that penetrated from the lateral surface through to the proximal surface. In addition to the hits discussed above, two lumbar vertebrae and a thoracic vertebra were broken by hits from points No 11, No 12

Figure 3. Right goat scapula with four holes pierced by spear point hits. The bone is broken in two pieces. Scale is 5 cm.

Figure 4. Right (unfused) goat humerus with tip of spear point (No 16) embedded through the proximal end. Scale is 5 cm.

and No 13, respectively. These three hits resulted in the retirement of points No 12 and No 13, which had minor fragments broken from their tips (losing 5 mm and 7 mm, respectively). Point No 11 had no detectable damage as a result of this throw.

Other Antler Projectile Research

The above results confirm those of other researchers. In perhaps the earliest experiment of this nature, Tyzzer (1936) replicated Northeastern American Algonkian points made of long bone shafts. He noted the occurrence of resharpening on some archaeological points, indicating their extendable use life after tip damage had occurred. Among his own replicated points (made of cattle long bone), he noted that damage generally did not occur when these were fired repeatedly into a loam bank. Points commonly broke upon striking rock, usually resulting in terminal damage (Tyzzer, 1936: 267). One bone point withstood 25 shots into a loam bank without any significant damage, then 15 more shots into a gravel bank before fracture.

Guthrie (1983) examined the suitability for projectile point usage of caribou (*Rangifer tarandus*) antler, elk (*Cervus elaphus*) antler, moose (*Alces alces*) antler, birch wood, and large mammal long bone shafts. A freshly killed bull moose (350 kg) was the target for points mounted on 2 m fibreglass shafts fired from a compound bow at a range of 5 m (force equivalent to throws at 25–30 m). For all point types penetration tended to be greatest in the rib area, since the muscles here are stretched tight and cushion impact less.

Moose antler (which has a thin cortical layer from which to manufacture points) and birch wood performed poorly in these experiments in terms of durability and penetration. Bone points penetrated well, but broke easily. This type lasted on average less than half as long as caribou antler points and had even shorter use life than the latter type when each struck hard ground. The top performing materials were caribou and elk antler, lasting on average 3·47 and 2·47 throws per point, respectively, without damage. Each also had superior penetrating ability, averaging 28·00 cm and 23·43 cm, respectively, in penetration depth (Guthrie, 1983: 288). Caribou antler outperformed elk antler, since the cortex of the former averages 10 ± 1 mm in thickness, about 2 mm thicker on average than the latter (Guthrie, 1983: 285–287). Larger implements therefore were fashioned, with durability increasing with antler thickness.

In keeping with the results of this study, tips followed by hafting areas were the most subject to breakage (Guthrie, 1983: 291). The shorter use life for Guthrie's antler points is most likely a function of the much larger size of his target, a 4-year-old moose with its hide still on, and by greater propulsive force applied to his projectiles. Even with this shorter use life, Guthrie's antler tip damage was usually slight enough to be repaired easily by resharpening. From his experimentation Guthrie concluded that Clovis (stone point) industries in North America could in fact have been derived from Beringian (microblade-armed caribou antler point) industries. Caribou antler was found to be such a more durable and penetrating projectile point material than stone that Clovis progenitors perforce gave up the use of the former only as they spread south into America and lost their abundant supply (Guthrie, 1983: 277).

Arndt and Newcomer (1986) experimented with the intent to induce breakage upon replicated antler, long bone and ivory points. Their targets were a fresh ewe carcass and a lamb shoulder backed up by three scapulae and a pelvis of a *Bos taurus* (Arndt & Newcomer, 1986: 166). Points (double bevelled) were mounted on hardwood arrow shafts with pine resin/beeswax mastic and fired at a range of 5–7 m with a 49 lb. draw bow. Since these authors' intent was to induce damage by aiming for bone, data on use life can not be calculated from their study. They did, however, note that damage occurred only when thick cortical bone was struck squarely (Arndt & Newcomer, 1986:

166), with hits into meat alone or thin bone generally not causing damage.

Accrued damage was in three categories. Most damage was tip breaks, taking the form of slight crushing, rounding or bevelled breaks. They note that tip damage was usually repairable with a few minutes of resharpening. For my experiment, tip damage of the kind noted in this study was the most prevalent, and was as easily repairable. Middle breaks were either oblique or transverse. Unlike post-depositional transverse breaks which tend to be smooth, impact induced (fresh) breaks tend to be jagged (observed in my experiment and at El Juyo). Basal breaks of the hafting area also occurred, with damage similar as noted for middle breaks. These damage observations agree with the findings of my experiment in all particulars.

Bergman (1987) experimented with a similar setup as above. He replicated Paleolithic points from Ksar Akil (Lebanon) of antler and long bone, mounted on arrow shafts with resin and beeswax mastic and various bindings. These projectiles were fired at 5–15 m with a 40 lb. draw bow into a target of 15 cm thick meat backed by two cow scapulae (Bergman, 1987: 118). Most of his points penetrated the meat and struck bone, with 2 points piercing scapulae. At a variance with my results and the other studies discussed above, most of his points suffered damage upon their first impact (Bergman, 1987:123). These results are partially explained by the thinness of the points used and by most shots striking bone. Points in this study were of red deer antler, 8–5 mm thick and of fallow deer (*Dama dama*) antler, about 4 mm in cortical thickness (Bergman, 1987:118). He did note that most breakages were only slight damage to the tip, and could be repaired easily.

These experiments among others (Knecht, 1991*b*, 1997) confirm the general properties of antler projectile points. They are easy to fashion from soaked antler with cutting or grinding tools, but take more time to complete than simple stone points. They are extremely durable, withstanding repeated impacts into flesh, thin bone or soil without breaking. When damage does occur, the most common form is slight crushing or chipping of the tip, which can be easily resharpened with no loss of function. Penetration is also excellent, with fatal wounds to targets a likely result.

Comparison with Stone Projectile Tip Experiments

Experiments by other researchers using a range of replicated stone point types under differing conditions have yielded very different results concerning stone point durability and use life. Flenniken (1985) experimented with 4 to 5 cm long obsidian points on a target of two live, large adult male feral goats. Each goat weighed approximately 75 kg. The 11 points used were mounted on hardwood shafts with sinew binding and delivered on 2 m softwood spears thrown a ‘‘short distance’’ by hand. Only one obsidian point was not damaged after one impact on target. No points were damaged as a result of misses, possibly due to the fact the target animals were trapped in deep snow to impede their movements.

Flenniken (1985: 270) notes that animal movement is an important factor in point damage. Some tip fragments from a single point travelled more than 40 cm within a goat body: from the point of impact in the middle of the animal’s left side to its throat. Clearly, the muscular exertions of a wounded animal potentially can break a spear point after impact and penetration have occurred. In addition, a wounded animal dragging a spear may cause point damage by the leverage exerted by the spear shaft striking nearby obstacles (Odell & Cowan, 1986: 202). Since all of the fractures induced in Flenniken’s experiment (1985: 273) were the result of artefact bending (i.e. lateral stress), animal motion may be an important factor in the very short average use life of these replicated obsidian points. Odell (1981) notes that this type of damage occurs frequently on stone points as a direct result of impact at less than a right angle. This situation must occur frequently in actual hunting episodes, with the resulting potential to cause point damage through bending stress.

The results obtained by Odell & Cowan (1986) indicate a low average use life for their replicated chert projectile points. Their points were mounted as spear points and as arrow heads. Spears were thrown 4 to 5 m and arrows were propelled twice that distance at a target of two to four fresh dog carcasses placed in close proximity. The 40 retouched points in the experiment ranged in length from 17 to 78 mm. Their average use life was 3·65 throws before retirement, including high percentages of throws that bounced off the target after failing to penetrate. Few throws or shots resulted in misses.

Titmus & Woods (1986) also experimented with obsidian points. Their replicated points averaged over 4 cm in length and were hafted to 18 cm foreshafts mounted on 119 cm darts. These were hurled with the aid of an atlatl at a variety of targets (sand, gravel, cinders, loose bark, dirt, sod and wood) in order to induce breakage. The average use life of the 30 points hafted and hurled was 2·1 throws before damage compelled retirement.

Bergman & Newcomer (1983) experimented with replicated flint points from Early Upper Paleolithic industries of Ksar Akil (Lebanon). These points (averaging 55 mm long by 16 mm wide by 4 mm thick) were mounted on arrow shafts and fired from a 48 lb. draw bow into a meat slab 15 cm thick backed by ox scapulae (Bergman & Newcomer, 1983: 240). The range was 1–3 m. While the authors give no data on use life (their intent was to induce damage in order to study flint breakage patterns), the damage accrued to points tended to be more severe than in the experiment by Bergman (1987) using a similar setting with osseous projectile tips.

Extensive recent research has been carried out utilizing replicated Solutrean flint points, mounted with ligature and/or resin onto shafts and fired from a crossbow into the undressed carcasses of domesticated goats (Chadelle, Geneste & Plisson, 1991; Morel, 1991; 1993; Geneste & Plisson, 1993). While the experimenters' design was to induce projectile breakage and skeletal impact damage, they do note that fractures upon first impact were numerous, and that 20% of damage included leaving behind embedded fragments. Pseudo-burinations also resulted from some impacts. They also note that many more fragments were left behind in the experimental carcasses, which in a real hunting setting would have made their way back to the site transported in butchered meat (Morel, 1991, 1993). While use life was not indicated for these points, damage sufficient to retire a point was common.

Callahan (1994) describes his earlier experiments where replicated Clovis points were hafted and launched with a spearthrower at an elephant carcass. A wide array of hafting and fletching methods and foreshaft systems were used. No data on use life are presented, but Callahan notes that points broke on each impact into frozen meat. This situation was rectified by throwing into the thawed carcass, whereby no further damage occurred. No information on the number of impacts or whether bones were struck was presented. Callahan does note that significant penetration through tough elephant hide was only possible by use of a spearthrower. Use life in this case was above the norm for lithic points, but their propensity to break upon impact into hard objects is again illustrated. Frison (1989) experimented on fresh elephant carcasses using Clovis weaponry. Seven obsidian, quartzite, silicified sediment and chert points were employed. Two broke very early, one as the result of a hafting mishap, but one more point survived the entire set of experiments unbroken. The remaining four points each broke at least twice, but were rejuvenated into functional points.

The greater durability of antler as a raw material for projectile points is evident when these results are compared. The experimental antler spear points of this study had an average use life of just under 10 throws. In addition, 17 of 20 were retired with minimal damage to their tips and could have been readily resharpened, even in the field, or used just as they were with little reduction in performance. The damage sustained by the stone points in the cited experiments tended to be far more substantial and was often irreparable.

The experiment which had the shortest use life for its projectile points utilized the most realistic hunting situation: Flenniken's (1985) live feral goat targets. The results of this experiment reflect the most closely an actual hunting situation, since it was the only one to include the motion of wounded animals as a factor in point breakage. The use life of antler points undoubtedly would have been lower had the author used live animal targets in a more natural setting. It is doubtful, however, that the same high rate of breakage (10 of 11 of Flenniken's obsidian points broke after one impact) would have been sustained. Antler's ability to withstand lateral stress (Currey, 1979, 1989; Chapman, 1981) is far greater than that of stone tool raw materials such as chert or obsidian (Crabtree & Davis, 1968). Hence, its performance in an actual hunting situation can be expected to exceed that of lithic materials.

The experiments with replicated Clovis points (Frison, 1989; Callahan, 1994) suggest that some hafting methods reduce the likelihood of lithic point damage. With their long lateral flutes, Clovis-style points can be hafted deeply recessed into a wooden slot. The cutting edge is still exposed, and the fluting reduces the protrusion of the wooden hafting element. The parallel lateral supports, apart from holding the point securely, also brace it against lateral stress. The fluting on Clovis points therefore may have been a deliberate adaptation to increase the use life of lithic points.

The ability of the replicated antler points to graze past ribs and penetrate fully into the thoracic cavity (with its vital organs) is a quality unlikely to be duplicated in a stone point. This ability is a function of antler's impact resilience, narrow gauge of manufacture, and flexibility. Unless a stone point struck in the proper rotational aspect, it is unlikely to have sufficient clearance to fit cleanly between two ribs of a goat-sized mammal. Stone points narrow enough to fit between the ribs of small- to medium-sized game animals run the risk of excessive fragility. As mammal body size increases, so does the space afforded between ribs, but the ribs themselves become more robust (and more likely to damage a projectile point). The hypothetical stone projectile point so hurled and impacting none the less may have sufficient penetrative force to carry into an animal's body and inflict a crippling or lethal wound, but it is far less likely that the stone point would survive such an impact without significant damage than for a comparable antler point.

The array of experimental settings (varying in types of propulsion, projectile point mounting, size and morphology of points, size of spear or dart used, distance thrown, force used, criteria for retirement, number of misses, object or substrate hit if the target is not), and the nature of the target itself, conspire to make direct quantitative comparison of the cited studies with each other and with that of this study difficult. This variety of experimental settings itself, encompassing multiple propulsive and target scenarios, is more likely to encompass the many possible hunting situations practised by Cantabrian Lower Magdalenians. While substantial evidence exists that the spearthrower was employed and perhaps the bow (Bergman, 1993; Cattelain, 1997), their use in any given hunting situation cannot be assumed. Antler spearpoints show an inherently longer use life across a range of experimental situations. Raw material analysis (Currey, 1979, 1989; Odell, 1981; MacGregor, 1985) indicates that this difference is likely to be exaggerated in actual hunting practice. Antler's inherent flexibility (even more so than bone) preadapts projectile points made from it to resist unexpected stresses caused by target misses, wounded animal movement, lateral bending during and after impact, and extraction by hunters.

Solutrean/Lower Magdalenian Hunting Transitions

This study reinforces the interpretation that the change from Solutrean to Lower Magdalenian hunting kits involved not a stylistic change in implements, but directed change shaped by different functional needs over time. While the antler points of Lower Magdalenian (and Solutrean) assemblages served the same essential role as stone Solutrean points (projectile tips), they had significant functional differences. That by the beginning of the Cantabrian Lower Magdalenian around 16,500 BP stone projectile points had been demoted in favour of antler ones reflects and coincides with other changes occurring in the latter half of the Upper Paleolithic in Cantabrian Spain. These are increases in intensification of resource exploitation, the number of sites, and the number of types of sites, coinciding with population increase (Freeman, 1973, 1975, 1981, 1994; Davidson, 1976; Straus, 1977, 1985, 1986, 1991*a*, 1992; Bailey, 1983; Bailey & Davidson, 1983; Clark & Straus, 1983; Butzer, 1986).

I wish to avoid labelling antler spear points as ''better'' in any absolute sense than stone ones such as Solutrean foliate points. Stone spear points do in general have the very important advantage over antler ones in their potential to inflict a larger, more jagged and perhaps more damaging wound (Christenson, 1986: 117). Modern broadhead arrows (more analogous in form to stone points than antler ones) are armed with wide cutting edges to sever major blood vessels and cause more rapid haemorrhaging. This additional hunting benefit is gained by inset microblades along an antler point shaft, which was an occasional practice among Magdalenian hunters (Allain & Descouts, 1957; Leroi-Gourhan, 1983; Peterkin, 1993). The fragmentation that a stone point can undergo within the body of a still-moving animal may itself be a hunting benefit, since more damage is caused to the animal. Wide stone-tipped projectiles also may be much more difficult for a wounded animal to remove. An animal that is dragging a spear, snagging and bumping obstacles, has a slower escape pace and is easier to track. Stone points also may be quicker to make on average (Bergman & Newcomer, 1983; Fischer, 1985; Flenniken & Raymond, 1986; Bergman, 1987), an important consideration under field conditions where rapid improvization may be necessary from time to time. Additional flint blanks can be carried and new points manufactured on the spot while on a hunt. Antler spear points require preparation of material (soaking for softening, much cutting for blank manufacture) and must be ground or scraped into form, a slower process than flint knapping. Stone points also provide a cutting edge useful for other improvized tasks, if not in some cases even serving as knives (Christenson, 1986). An antler point is not superior in an absolute sense, but offers a different set of characteristics.

The use of antler spear points may be judged superior to the use of stone points under a certain set of hunting circumstances. Following Bleed (1986), overall hunting systems can be analysed within the parameters of Reliable versus Maintainable systems. Reliable systems would seem to be universally optimal, but they are very costly to produce. Their characteristics include over-designed components, use below full capacity, carefully fitted parts and good craftsmanship, and redundancy (Bleed, 1986: 739). The expense incurred with their use is worthwhile in cases where the cost of system failure is high or where down-time is predictable. Maintainable systems are characterized in part by their ability to be repaired in the field, their lower cost of manufacture and their ease of repair or replacement. This type of system may be more desirable than a more reliable (but more expensive) system in cases where need schedule is unpredictable or where there is a more opportunistic hunting strategy: game is hunted more often in smaller numbers, so failure of the system is not as great a loss.

In this light, the transition from Solutrean to Lower Magdalenian hunting kits is also a shift from a less costly but more maintainable system to a more costly but more reliable one. This change mirrors the transition in subsistence strategy that occurred over this time in Cantabrian Spain. The faunal exploitative strategy of the Solutrean is more opportunistic, shifting to a more planned specific-exploitative strategy in the Lower Magdalenian where the planned ambush of large groups of red deer, ibex and other game became more prevalent (Freeman, 1973, 1975, 1981; Bailey, 1983; Clark & Straus, 1983; Klein *et al*., 1981; Klein & Cruz Uribe, 1987). For planned, seasonal harvest of game herds a reliable system becomes more desirable: equipment must function well and within a certain time frame only or a rare opportunity is lost. Such an exploitive system for salmon was also practised among Cantabrian Lower Magdalenians (Pokines & Krupa, 1997). This additional expense may be less desirable where the predominant hunting strategy is the opportunistic killing of singular, more frequently encountered game: failure is not so costly.

The longer manufacturing process of antler spear points was deemed a worthwhile trade-off for their greater durability, use life and penetrating potential by Cantabrian Lower Magdalenian hunters. The time needed for soaking, cutting, shaping and hafting antler points may have been consigned to periods of down-time between large, planned hunts where whole herds of red deer or ibex were surrounded and driven into natural or human-made traps or mires for slaughter. This engineering choice was also prevalent in other portions of Western Europe during this period. Gordon (1988) interprets data from the French Magdalenian to indicate that human groups migrated with vast reindeer herds. In this hunting context, crucial windows of opportunity came at certain key ambush points along the seasonal migratory path of the reindeer. Mistiming could be fatal to the hunters. Antler points, while taking more effort to make, were worth the additional time investment, since they were less likely to fail at the crucial window of opportunity afforded by the organized surround of a large herd.

Summary

Experimentation with replicated antler projectile points demonstrates their high durability. Their great strength and flexibility translate into a longer use life and an ability to penetrate (by grazing past or punching through thin bone) into body cavities housing vital organs. Their durability far surpasses that of experimentally reproduced and propelled stone points. While antler points represent a larger time investment, their greater reliability correlates with the dominant hunting strategy of the Cantabrian Lower Magdalenian: a shift towards the planned harvest of large herds of red deer or ibex at one time. This greater time investment was to some degree offset by the rise in the prevalence of quadrangular forms, which involved less reshaping from the antler blanks produced. Their archaeological breakage pattern indicates they were generally used until accruing terminal damage, thereby increasing their already long use life. The choice of antler projectile points fits within this system of intensified and less opportunistic faunal exploitation, given the greater need for reliability in a projectile point. Future projectile experimentation should include head to head experimentation with stone, antler and composite points in a variety of propulsive and target scenarios, in order to quantify better their inherent properties across a full spectrum of hunting situations. Any further insights concerning the operation of projectile points within a hunting system will give a fuller picture of the overall ecological adaptation of these Cantabrian Lower Magdalenian hunters.

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References

Allain, J. & Descouts, J. (1957). A propos d'une baguette a rainure armée de silex découverte des le Magdalénien de St. Marcel. *L'Anthropologie* **61,** 503–512.

Arndt, S. & Newcomer, M. (1986). Breakage patterns on prehistoric bone points: An experimental study. In (D. A. Roe, Ed.) *Studies in the Upper Palaeolithic of Britain and Northwest Europe*. British Archaeological Reports International Series **296,** pp. 165–173.

Bailey, G. (1983). Economic change in Late Pleistocene Cantabria. In (G. Bailey, Ed.) *Hunter-Gatherer Economy in Prehistory*. Cambridge: Cambridge University Press, pp. 149–165.

Bailey, G. N. & Davidson, I. (1983). Site exploitation territories and topography: two case studies from Palaeolithic Spain. *Journal of Archaeological Science* **10,** 87–115.

Barandiarán, I. (1981). Industria osea. In (J. González Echegaray & I. Barandiarán, Eds) *El Paleolitico Superior de la Cueva del Rascaño (Santander)*. Santander: Centro de Investigación y Museo de Altamira, Monografías **3,** pp. 97–164.

Barandiarán, I. (1987). Industria osea Paleolitica de la Cueva Del Juyo, excavaciones de 1978 y 1979. In (I. Barandiarán, L. G. Freeman, J. González Echegaray & R. G. Klein, Eds) *Excavaciones en la Cueva Del Juyo*. Santander: Centro de Investigación y Museo de Altamira, Monografías **14,** pp. 161–194.

Barandiarán, I., Freeman, L. G., González Echegaray, J. & Klein, R. G. (Eds). (1987). *Excavaciones en la Cueva Del Juyo*. Santander: Centro de Investigación y Museo de Altamira, Monografías **14**.

Bergman, C. A. (1987). Hafting and use of bone and antler points from Ksar Akil, Lebanon. In (D. Stordeur-Yedid, Ed.) *La Main et l'Outil*. Lyon: Travaux de la Maison de l'Orient, **15,** pp. 117–126.

Bergman, C. A. (1993). The development of the bow in Western Europe: A technological and functional perspective. In (G. L. Peterkin, H. M. Bricker & P. Mellars, Eds) *Hunting and Animal Exploitation in the Later Paleolithic and Mesolithic of Eurasia*. Archeological Papers of the American Anthropological Association **4**. Washington: American Anthropological Association, pp. 95–105.

Bergman, C. A. & Newcomer, M. H. (1983). Flint arrowhead breakage: examples from Ksar Akil, Lebanon. *Journal of Field Archaeology* **10,** 238–243.

Bleed, P. (1986). The optimal design of hunting weapons: Maintainability or reliability. *American Antiquity* **51,** 737–747.

Broglio, A., Chelidonio, G. & Longo, L. (1993). Analyse morphologique et fonctionnelle des pointes à cran de l'Épigravettien ancien. In (P. C. Anderson, S. Beyries, M. Otte & H. Plisson, Eds) *Traces et Fonction: Les Gestes Retrouvés*. Liège: Etudes et Recherches Archéologiques de l'Université de Liège **50,** vol. I, 31–39.

Bryant, L. D. & Maser, C. (1982). Classification and distribution. In (J. W. Thomas & D. E. Toweil, Eds) *Elk of North America*. Harrisburg: Stackpole Books, pp. 1–59.

Butzer, K. W. (1986). Paleolithic adaptations and settlement in Cantabrian Spain. In (F. Wendorf & A. E. Close, Eds) *Advances in World Archaeology* **5**. Orlando: Academic Press, pp. 201–252.

Callahan, E. (1994). A mammoth undertaking. *Bulletin of Primitive Technology* **1,** 23–39.

Cattelain, P. (1997). Hunting during the Upper Paleolithic: bow, spearthrower, or both? In (H. Knecht, Ed.) *Projectile Technology*. New York: Plenum Publishing, pp. 213–240.

Cattelain, P. & Perpère, M. (1993). Tir expérimental de sagaies et de flèches emmanchées de pointes de la Gravette. *Archéo-Situla* **17–20,** 5–28.

Chadelle, J.-P., Geneste, J.-M. & Plisson, H. (1991). Processus foncionnels de formation des assemblages technologiques dans les sites du Paléolithique supérieur. In *25 Ans d'Etudes Technologiques*

en Préhistoire. XIe Rencontres Internationales d'Archéologie et d'Histoire d'Antibes. Juan-les-Pins: Éditions APDCA, pp. 275–287.
Chapman, D. I. (1981). Antler structure and function—a hypothesis. *Journal of Biomechanics* **14,** 195–197.
Christenson, A. L. (1986). Projectile point size and projectile aerodynamics: An exploratory study. *Plains Anthropologist* **31,** 109–128.
Clark, G. A. & Straus, L. G. (1983). Late Pleistocene hunter-gatherer adaptations in Cantabrian Spain. In (G. Bailey, Ed.) *Hunter-Gatherer Economy in Prehistory*. Cambridge: Cambridge University Press, pp. 131–148.
Clutton-Brock, T. H., Guiness, F. E. & Alban, S. D. (1982). *Red Deer: Behavior and Ecology of Two Sexes*. Chicago: University of Chicago Press.
Crabtree, D. E. & Davis, E. L. (1968). Experimental manufacture of wooden implements with tools of flaked stone. *Science* **159,** 426–428.
Currey, J. D. (1979). Mechanical properties of bone tissues with greatly differing functions. *Journal of Biomechanics* **12,** 313–319.
Currey, J. D. (1989). Strain rate dependence of the mechanical properties of reindeer antler and the cumulative damage model of bone fracture. *Journal of Biomechanics* **22,** 469–475.
Curtis, E. S. (1911). *The North American Indian* **8**. Norwood, MA: Plimpton Press.
Davidson, I. (1976). Seasonality in Spain. *Zephyrus* **26–27,** 175–182.
Fischer, A. (1985). Hunting with flint-tipped arrows: results and experiences from practical experiments. In (C. Bonsall, Ed.) *The Mesolithic in Europe*. Edinburgh: John Donald, pp. 29–39.
Flenniken, J. J. (1985). Stone tool reduction techniques as cultural markers. In (M. G. Plew, J. C. Woods & M. G. Pavesic, Eds) *Stone Tool Analysis: Essays in Honor of Don E. Crabtree*. Albuquerque: University of New Mexico Press, pp. 265–276.
Flenniken, J. J. & Raymond, A. W. (1986). Morphological projectile point typology: Replication experimentation and technological analysis. *American Antiquity* **51,** 603–614.
Freeman, L. G. (1973). The significance of mammalian faunas from Paleolithic occupations in Cantabrian Spain. *American Antiquity* **38,** 3–44.
Freeman, L. G. (1975). By their works you shall know them: Cultural developments in the Paleolithic. In (G. Kurth & I. Eibl-Eibesfeldt, Eds) *Hominisation und Verhalten*. Stuttgart: G. Fischer, pp. 234–261.
Freeman, L. G. (1981). The fat of the land: notes on Paleolithic diet in Iberia. In (R. S. O. Harding & G. Teleki, Eds) *Omnivorous Primates*. New York: Columbia University Press, pp. 104–165.
Freeman, L. G. (1994). Paleolithic polygons: Voronoi tesserae and settlement hierarchies in Cantabrian Spain. In *Espacio, Tiempo y Forma, Series 1, Prehistoria* **7**. Madrid: Universidad Nacional de Educación a Distancia, pp. 43–61.
Frison, G. C. (1989). Experimental use of Clovis weaponry and tools on African elephants. *American Antiquity* **54,** 766–784.
Geneste, J.-M. & Plisson, H. (1993). Hunting technologies and human behavior: Lithic analysis of Solutrean shouldered points. In (H. Knecht, A. Pike-Tay & R. White, Eds) *Before Lascaux: The Complex Record of the Early Upper Paleolithic*. Boca Raton: CRC Press, pp. 117–135.
Geneste, J.-M. & Maury, S. (1997). Contributions of multidisciplinary experimentation to the study of Upper Paleolithic projectile points. In (H. Knecht, Ed.) *Projectile Technology*. New York: Plenum Publishing, pp. 165–189.
González Echegaray, J. (1960). El Magdaleniense III de la Costa Cantábrica. *Boletín de Seminario de Estudios de Arte y Arqueologia,* Universidad de Valledolid **26,** 69–100.
González Echegaray, J. & Barandiarán, I. (Eds). (1981). *El Paleolitico Superior de la Cueva del Rascaño (Santander)*. Santander: Centro de Investigación y Museo de Altamira, Monografías **3**.
González Morales, M. R. (1986). La Riera bone and antler artifact assemblages. In (L. G. Straus & G. A. Clark, Eds) *La Riera Cave*. Arizona State University Anthropological Research Papers **36,** pp. 209–218.
Gordon, B. C. (1988). *Of Men and Reindeer Herds in French Magdalenian Prehistory*. British Archaeological Reports International Series **390**.
Guthrie, R. D. (1983). Osseous projectile points: Biological considerations affecting raw material selection and design among Paleolithic and Paleoindian peoples. In (J. Clutton-Brock & C. Grigson, Eds) *Animals and Archaeology*. British Archaeological Reports International Series **163,** pp. 273–294.
Klein, R. G. & Cruz Uribe, K. (1987). La fauna mamífera del yacimiento de la Cueva de ''El Juyo''. Campañas de 1978 y 1979. In (I. Barandiarán, L. G. Freeman, J. González Echegaray & R. G. Klein, Eds) *Excavaciones en la Cueva Del Juyo*. Santander: Centro de Investigación y Museo de Altamira, Monografías **14,** pp. 97–120.
Klein, R. G., Wolf, C., Freeman, L. G. & Allwarden, K. (1981). The use of dental crown heights for constructing age profiles of red deer and similar species in archaeological samples. *Journal of Archaeological Science* **8,** 1–31.
Knecht, H. (1991*a*). The role of innovation in changing Early Upper Paleolithic organic projectile technologies. *Techniques et Culture* **17–18,** 115–144.
Knecht, H. (1991*b*). *Technological Innovation and Design During the Early Upper Paleolithic: A Study of Organic Projectile Technologies*. Ph.D. thesis, New York University.
Knecht, H. (1993). Splits and wedges: the technique and technology of Early Aurignacian antler working. In (H. Knecht, A. Pike-Tay & R. White, Eds) *Before Lascaux: The Complex Record of the Early Upper Paleolithic*. Boca Raton: CRC Press, pp. 137–162.
Knecht, H. (1997). Projectile points of bone, antler, and stone: Experimental explorations of manufacture and use. In (H. Knecht, Ed.) *Projectile Technology*. New York: Plenum Publishing, pp 191–212.
Krupa, M. (1994). *Limpets and Other Marine Molluscs: An Evaluation of Their Archeological Significance at El Juyo and Other Paleolithic Sites in Northern Spain*. MA thesis, University of Chicago.
Krupa, M. (1996). Effects of processes of deposition, taphonomy and excavation on the interpretation of fish remains from Upper Paleolithic sites in western Europe. Paper presented at the 61st Annual Meeting of the Society for American Archaeology, April 11, New Orleans, LA.
Leroi-Gourhan, A. (1983). Un tête de sagaie à armature de lamelles de silex à Pincevent (Seine-et-Marne). *Bulletin de la Société Préhistorique Française* **80,** 154–156.
MacGregor, A. G. (1985). *Bone, Antler, Ivory and Horn: The Technology of Skeletal Materials Since the Roman Period*. London: Croom Helm.
Mohler, L. L. & Toweill, D. E. (1982). Regulated elk populations and hunter harvests. In (J. W. Thomas & D. E. Toweill, Eds) *Elk of North America*. Harrisburg: Stackpole Books, pp. 561–597.
Morel, P. (1991). Aspects archéozoologiques de las chasse préhistorique: impacts expérimentaux sur le squelette et leurs enseignments. *Verhandlungen der Naturforschenden Gesellschaft Basel* **101,** 41–47.
Morel, P. (1993). Impacts de projectiles sur le gibier: quelques éléments d'une approche expérimentale. In (P. C. Anderson, S. Beyries, M. Otte & H. Plisson, Eds) *Traces et Fonction: Les Gestes Retrouvés*. Liège: Etudes et Recherches Archéologiques de l'Université de Liège **50,** vol. I, 31–39.
Newcomer, M. H. (1974). Study and replication of bone tools from Ksar Akil (Lebanon). *World Archaeology* **6,** 138–153.
Noe-Nygaard, N. (1974). Mesolithic hunting in Denmark illustrated by bone injuries caused by human weapons. *Journal of Archaeological Science* **1,** 217–248.
Odell, G. H. (1981). The mechanics of use-breakage of stone tools: some testable hypotheses. *Journal of Field Archaeology* **8,** 197–210.
Odell, G. H. & Cowan, F. (1986). Experiments with spears and arrows on animal targets. *Journal of Field Archaeology* **13,** 195–212.
Peterkin, G. L. (1993). Lithic and organic hunting technology in the French Upper Paleolithic. In (G. L. Peterkin, H. M. Bricker & P. Mellars, Eds) *Hunting and Animal Exploitation in the Later*

Paleolithic and Mesolithic of Eurasia. Archaeological Papers of the American Anthropological Association **4**. Washington: American Anthropological Association, pp. 49–67.
Pokines, J. T. (1993). *Antler Points from El Juyo (Santander, Spain): Form, Manufacture and Parameters of Use*. MA thesis, University of Chicago.
Pokines, J. T. & Krupa, M. (1997). Self-barbed antler spear-points and evidence of fishing in the Late Upper Paleolithic of Cantabrian Spain. In (H. Knecht, Ed.) *Projectile Technology*. New York: Plenum Publishing, pp. 241–262.
Shea, J. J. (1993). Lithic use-wear evidence for hunting in the Levantine Middle Paleolithic. In (P. C. Anderson, S. Beyries, M. Otte & H. Plisson, Eds) *Traces et Fonction: Les Gestes Retrouvés*. Liège: Etudes et Recherches Archéologiques de l'Université de Liège **50,** vol. I, 21–30.
Straus, L. G. (1977). Of deerslayers and mountain men: Paleolithic faunal exploitation in Cantabrian Spain. In (L. R. Binford, Ed.) *For Theory Building in Archaeology*. New York: Academic Press, pp. 41–76.
Straus, L. G. (1985). Stone Age prehistory of northern Spain. *Science* **230,** 501–507.
Straus, L. G. (1986). Late Würm adaptive systems in Cantabrian Spain: The case of Eastern Asturias. *Journal of Anthropological Archaeology* **5,** 330–368.
Straus, L. G. (1987*a*). Hunting in Late Upper Paleolithic Western Europe. In (M. H. Nitecki & D. V. Nitecki, Eds) *The Evolution of Human Hunting*. New York: Plenum Press, pp. 147–176.
Straus, L. G. (1987*b*). Upper Paleolithic ibex hunting in southwest Europe. *Journal of Archaeological Science* **14,** 163–178.
Straus, L. G. (1990). The original arms race: Iberian perspectives on the Solutrean phenomenon. In (J. Kozlowski, Ed.) *Feuilles de Pierre*. Etudes et Recherches Archéologiques de l'Université de Liège **42,** pp. 425–447.
Straus, L. G. (1991). Epipaleolithic and Mesolithic adaptations in Cantabrian Spain and Pyrenean France. *Journal of World Prehistory* **5,** 83–104.
Straus, L. G. (1992). *Iberia before the Iberians*. Albuquerque: University of New Mexico Press.
Titmus, G. L. & Woods, J. C. (1986). An experimental study of projectile point fracture patterns. *Journal of California and Great Basin Anthropology* **8,** 37–49.
Townsend, J. B. (1981). Tanaina. In (J. Helm, Ed.) *Handbook of North American Indians* **6**. Washington: Smithsonian Institution, pp. 623–626.
Tyzzer, E. E. (1936). The ''simple bone point'' of the shell-heaps of the Northeastern Algonkian area and its probable significance. *American Antiquity* **1,** 261–279.
Utrilla Miranda, P. (1981). *El Magdaleniense Inferior y Medio en la Costa Cantábrica*. Santander: Centro de Investigación y Museo de Altamira, Monografías **4**.