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ORIGINAL PAPER

Investigating the use of Paleolithic perforated batons: new evidence from Gough's Cave (Somerset, UK)

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Abstract

Perforated batons, usually made from a segment of antler and formed of a sub-cylindrical shaft and at least one perforation, have been documented across Europe from sites throughout the Upper Paleolithic and Mesolithic. The function of perforated batons is still debated. We present here three Magdalenian perforated batons from the site of Gough's Cave (Somerset, UK); these are unique to Britain and represent an important northern example of this artifact type. Our technological analysis revealed that the Gough's Cave perforated batons did not have a purely symbolic purpose, but were clearly used as tools as demonstrated by extensive use-wear on the perforations' edges and ancient fractures across both the distal parts and the shafts. The reconstruction of the *chaîne opératoire* suggests that the engraving of the deep curved lines within the perforation of each baton was a functional re-adjustment following the significant distortion of the perforation by use. Additionally, oblique bands of incisions were engraved on two of the batons' shafts possibly to provide grip on the smooth antler surface. Altogether, the modifications of the perforations and shafts of the three batons support the hypothesis that the Gough's Cave batons were used in a task associated with ropes and subjected to considerable forces. Their extensive use may be due to the rarity of the raw material (reindeer antler) in the Cheddar Gorge area during the Magdalenian. Extensive usage aside, the Gough's Cave batons fit typologically and share a number of features with other Magdalenian perforated batons. They can, therefore, add significant insight to the debate about the use of perforated batons.

Keywords Magdalenian · Osseous technology · Engraving · Use-wear

Introduction

Perforated batons are artifacts, usually made from a segment of antler, formed of an elongated sub-cylindrical shaft and a wider distal part of variable shape, with at least one circular or ovate perforation (Peltier 1992). Perforated batons have been found in archeological levels dating to the Upper Paleolithic (Aurignacian, Gravettian, Solutrean, and Magdalenian; Noiret 1990; Peltier 1992) and the Early Mesolithic (Osipowicz et al. 2017). Despite the large number of batons found (> 400), their use still remains enigmatic. No fewer than 40 functional hypotheses have been proposed, following debates that have persisted for over 150 years; the perforated baton has consequently become emblematic of our misunderstanding of some ancient objects' functions.

In the first publication that depicted Paleolithic perforated batons, Édouard Lartet and Henry Christy interpreted them as possible "symbols of authority" within a social group (Lartet and Christy 1867), having been impressed by the richness of the engraving and sculpting. Early prehistorians consequently referred to them as "bâtons de commandement". Further discoveries confirmed the high proportion of decorated batons (over 45% of batons; Rigaud 2001), as well as the elaborate stylistic and technical expression on some examples, including well-known masterpieces of Paleolithic art (Leroi-Gourhan 1971; Noiret 1990). However, the presence of use-wear and breakage across many perforations strongly suggest

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that they may have had a more practical use as tools or implements (Chauvet 1910; Didon 1911; Aymar 1912). As such, they have been inferred as arrow or spearhead straighteners (Dawkins 1874: 354–355; Leroi-Gourhan 1971), part of animal harnesses (Bahn 1976; Pigorini 1877), tent pegs (Peyrony 1934), rope making tools (Breuil 1956; Conard and Malina 2016; Kilgore and Gonthier 2014), catapult shafts (Glory 1964, 1965), spear throwers (Cook 2013; Underwood 1965), fire drills (Manos and Boutié 1996), and cable blockers (Rigaud 2001, 2004), among other interpretations.

Use-wear analyses and experimental archeology have brought significant information to the debate. Different types of use-wear have been documented on the edges of the perforations: concave distortions (*écrasement* in French), polishes, areas of distortion where the antler fibers extrude from their natural position (*broutage* in French), and in some cases, micro-striations (Glory 1964, 1965; Lompre 2003a; Mons 1976; Peltier 1992; Redondo Sanz 2016). Use-wear can also include polishes on the shaft that can partly obliterate decorations (Peltier 1992). The distribution of use-wear on the perforations of 135 batons was analyzed by Glory (1964, 1965), who highlighted their consistency. He has shown that most of the use-wear has an alternate organization, in which a worn area on one face corresponds to a symmetrical worn area on the diagonally opposite edge of the perforation. Moreover, they tend to have a slightly oblique orientation to the long axis of the shaft (Glory 1964). While this alternate use-wear pattern is the most common, different use-wear organizations have also been documented (Lompre 2003a; Mons 1976). A lot of evidence is available indicating the use of the artifact, though there is no consensus on whether the object being passed through the perforation was made of hard or supple material (Lompre 2003a). Additionally, André Rigaud highlighted that ~ 70% of Paleolithic perforated batons show breaks across the perforations and the shafts which could be associated with the use of the batons, despite the high flexibility and resistance of fresh (sensu *lato*) antler batons (Rigaud 2001, 2004). Indeed, Rigaud demonstrated that under the traction of a rope, breakages happen under a strength equivalent to the fall of a 10 kg load from a height of 2 m, which is not consistent with most of the hypotheses of use proposed thus far (Rigaud 2001, 2004).

We present here a detailed technological analysis of three Magdalenian perforated batons from Gough's Cave (Somerset, UK), engraved both within the perforation and on the shaft. Two of these batons (NHMUK PA E 7783 and NHMUK PA E 7782) were first described and illustrated by H. St. George Gray (in Parry 1928) and R. C. C. Clay (1929). More recently, Patricia McComb (1989) conducted a technological analysis of the first baton (NHMUK PA E 7783) and commented on the second (NMHUK PA E 7782) using available photos. Until this analysis, the third baton (NHMUK PV UNREG 4196) had never been previously studied. No detailed photos or micro-images had been published for any of the batons, and very limited description of the *chaîne opératoire* and traces of use had been presented. Comparisons with other perforated batons are also rare. The three perforated batons from Gough's Cave show particularly extended use-wear, re-working, and breaks or cracks. They can, therefore, add significant insight to the debate about the use of perforated batons from the European Upper Paleolithic.

Archeological context

Gough's Cave, discovered in the 1880s, is a large cave on the southern side of Cheddar Gorge, in south-western England. The cave was extensively excavated between 1927 and 1931 by R. F. Parry, by various excavators in the 1930s, 1940s, and 1950s, and by teams from the Natural History Museum (London) between 1986 and 1992. The finds mainly correspond to an important Magdalenian collection (Creswellian industry) and to some Mesolithic, Iron Age and Roman-British remains (Currant et al. 1989; Jacobi 2004; Parry 1928). Ultra-filtrated radiocarbon determinations suggest that the cave was occupied by Magdalenian hunters for a very short time span, possibly no more than two or three human generations, at ~ 14,700 cal BP (Jacobi and Higham 2009).

The excavated cave deposits were extremely rich, with notable Magdalenian artifacts (Charles 1989; Clay 1929; Tratman 1976), refitting flint debitage (Jacobi 2004) and butchered human (Andrews and Fernández-Jalvo 2003; Bello et al. 2011a, 2015, 2017; Cook 1986) and non-human bones (Bello et al. 2016; Currant 1986). Faunal remains and artifacts were found discarded in the same archeological deposits. The light weathering and rarity of random striae on bones suggest that sediment pressure, weathering, and trampling did not significantly alter the remains after their deposition (Bello et al. 2011a, 2011b). Breakage and incisions on bones can be associated with human activity and display micromorphological characteristics typical of modifications produced by stone tools. Characteristic breakage features include percussion pits and striae, and lunate scars, some with adhering flakes and anvil striae, which are consistent with humanly-induced fractures on fresh ('green') bone (Bello et al. 2016). Carnivore (non-human) chewing marks are also minimal, while human chewing marks are abundant (Bello et al. 2015).

The three perforated batons were found during different excavation campaigns; however, the exact location within the cave of two of them (NHMUK PA E 7783 and NHMUK PA E 7782) is unfortunately uncertain (Fig. 1):

NHMUK PA E 7783: The main portion of this baton was discovered in 1903, during excavations in 'Cheddar Man Fissure', under uncertain circumstances. It was suggested that the piece was found in proximity to the 'Cheddar Man' skeleton (Seligman and Parsons 1914), now directly dated to the

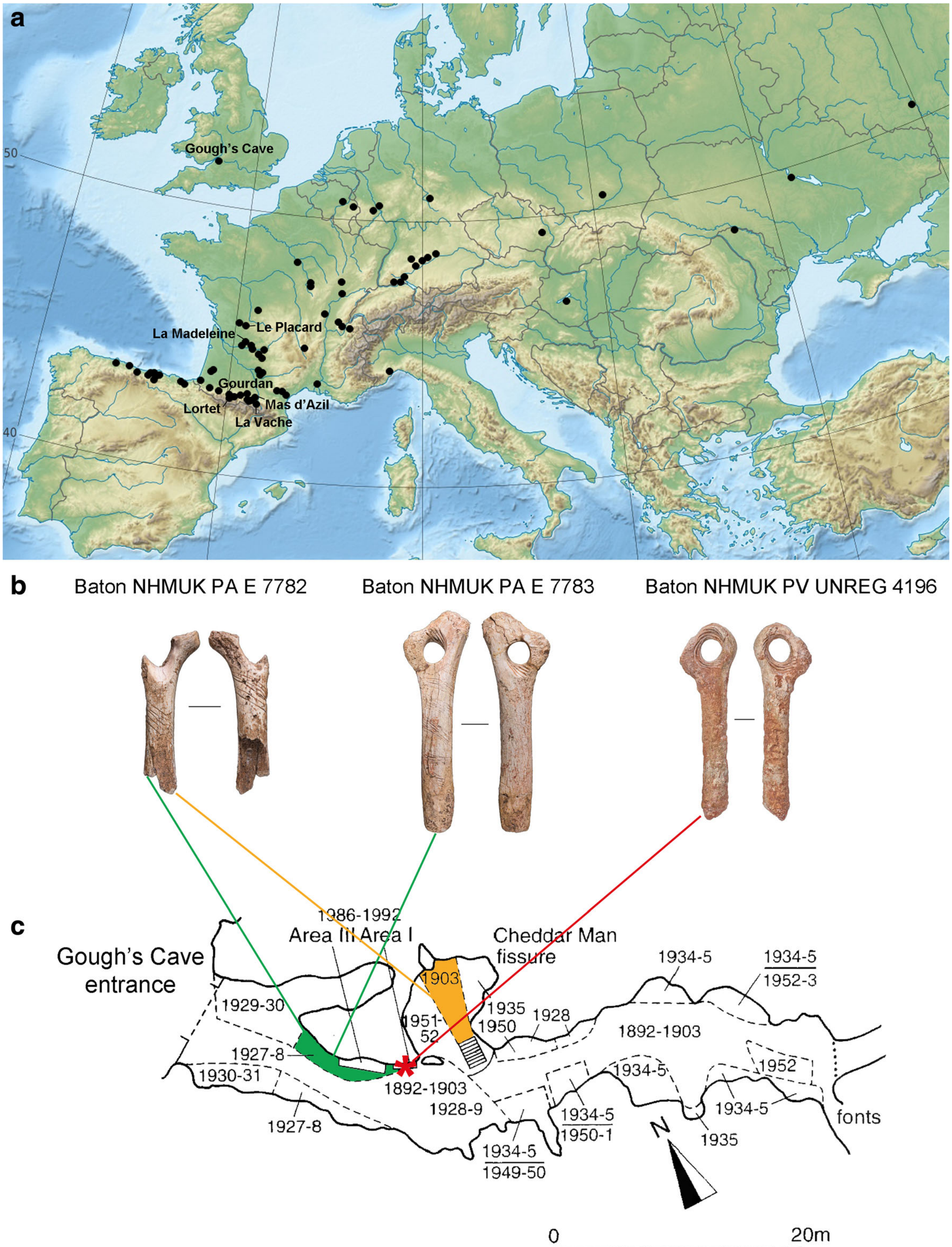


Fig. 1 Location of Gough's Cave and the archeological contexts of the batons. **A** Distribution of Paleolithic perforated batons across Europe (relief map from Wikimedia Creative Commons). **B** Photographs of the upper and lower faces of the three batons from Gough's Cave. **C** Gough's Cave plan (modified from Stringer 2000) showing the location of the batons within the cave

Mesolithic (Burleigh 1986), though this location was later contested (Donovan 1955; Jacobi 1985). A small fragment (51 × 11 × 6.5 mm) was found during Parry's excavation on the north side of the cave entrance in 1929–1930, at least 2.4 m from the main fragment (Parry 1930) and has been refitted and glued to the main part. This fragment comes from one of the richest layers of Magdalenian remains in the reddish clay deposits (spit 13).

NHMUK PA E 7782: The second perforated baton was also discovered during Parry's excavation in 1927 on the north side of the cave entrance. This baton was excavated from a deeper layer (spit 19) with a mix of gravel, waterworn pebbles, sand, and clay (Parry 1928), where it was associated with several Magdalenian flint artifacts (Clay 1929), suggesting potential disturbances to this part of the stratigraphy.

NHMUK PV UNREG 4196: The third baton was found in 1989, during the latter period of excavation led by the Natural History Museum. It comes from area I (square L101), on the north side of the cave entrance, from a layer of red silt and limestones, which matches sediment descriptions for previous Late Glacial finds in the Cave (Jacobi 2004; Jacobi and Higham 2009; Macphail and Goldberg 2003). This baton has been directly dated, originally with pretreatment by ion-exchanged gelatin determination (OxA-2797; Hedges et al. 1991), which yielded at age of 11,870 ± 110 BP, and was more recently re-dated to 12,535 ± 55 BP, following pretreatment by ultra-filtered gelatin determination (OxA-18,064; Jacobi and Higham 2009). Considering this baton's striking similarities to the two other perforated batons from Gough's Cave (McComb 1989), this radiocarbon age likely confirms the attribution of all three batons to the Magdalenian period.

Methods

The three batons were macroscopically and microscopically analyzed and standard measurements were performed (following Peltier 1992). For the purpose of this study, the main measurements taken and the terminology used for the different portions of the perforated batons are shown in Fig. 2. Generally, perforated batons are composed of a proximal part, the base of the shaft, an elongated sub-cylindrical shaft, and a wider distal part that varies in shape. The distal part of the Gough's Cave batons is composed of two short divergent branches (the lower and upper branches) and a large perforation. The perforated batons are made of the full thickness of the antler, and therefore do not show a cancellous inner surface. Hence, the distinction between an upper and a lower face is arbitrary. For the purpose of this analysis, we chose to call the 'upper face' the surface of the baton with the distal upper branch on the right and the distal lower branch on the left. The opposite face will be defined as the 'lower face'. Finally, the side on the right of the upper face will be indicated as the 'right side' and the opposite one as the 'left side'.

The maximum length of the baton is the distance between the proximal end and the most distal point of the distal upper branch. The length of the shaft and distal branches were measured from the edge of the perforation. The width and thickness of the shaft were taken at their maximum points. The diameters of the perforations were measured at both minimum and maximum points. The locations of the modifications around the perforation were numbered following Glory's diagram (areas 1 to 8; Fig. 2; Glory 1964), which is superimposed onto both faces of the baton's perforation. Area 1 starts on the left side of the perforation at a 90° angle to the shaft of the baton. The worn areas correspond to Glory's areas based upon their location around the perforation. For instance, in Fig. 2, the concave wear on the lower face of the baton mainly corresponds to Glory's areas 6 and 7. The maximum length of the worn areas was measured as the longest distance from the edge of the perforation, and the width was measured perpendicular to the length.

Detailed observations of the surfaces were undertaken in order to characterize anthropogenic traces left during the making and use of the objects. This technique follows the technological analytical method that has its origins in the analysis of lithic technology (Inizan et al. 1992) and that has been adapted to the study of bone industries (Averbouh 2000; Ramseyer 2004). Removal scars (negatives of flakes or other removals), sectioning grooves, scraping striations, engravings, areas of concave wear (distortion of the edge of the perforation resulting into a smooth concavity with a polished aspect), polishes, and fractures (breaks or cracks) were recorded, with their location on the baton, their dimensions, and their organization (pattern) noted. The sequence of these traces of working and use-wear was then analytically reordered according to their superposition to reconstruct the *chaîne opératoire*: debitage (sectioning of the branches), shaping (drilling of the hole), engraving, use and eventual re-working, and re-use. The English terminology for osseous technology (e.g., names of the traces and techniques) employed here refers to the *Multilingual lexicon of bone industries* (Averbouh 2016), when applicable.

Further detailed analyses were undertaken on the engravings. In this paper, the term engraving (sensu *lato*) is used in its general sense designating any hollowed patterns deliberately cut onto a plane, without any assumption about their purpose (marking, decoration, or functional adjustment). The perforated batons from Gough's Cave have been engraved by incision, a specific technique that is performed by creating superficial grooves on a surface via either a single passage of a tool or, more often, by multiple tool passages in a single direction (Averbouh 2000). This is the main engraving technique used during the Magdalenian and it is recognizable by specific characteristics at the start and end of each line (Fritz 1999). The general organization and production (direction and order of incisions) of the engravings were first assessed with the naked eye and subsequently with a binocular microscope (Nikon SMZ445, With 0.8×–3.5× zoom magnification and diascopic/episcopic LED Stand). In order to conduct micromorphometric analyses, the incisions were further analyzed using a Focus Variation Microscope (FVM), the Alicona Infinite Focus optical surface measurement system, and following the protocol developed by Bello and co-authors (Bello

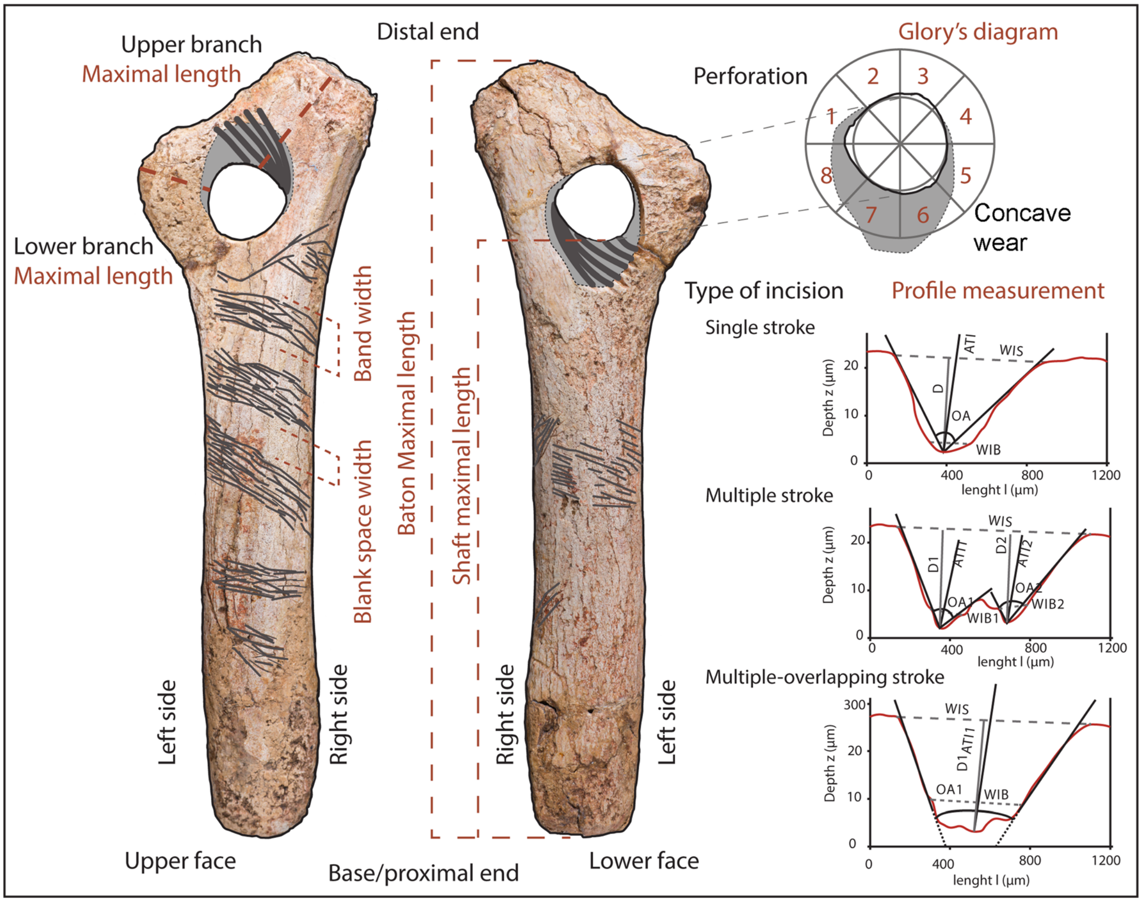


Fig. 2 Illustration of terminology and measurements used in the study of the perforated batons; Glory's diagram; types of incisions identified, and profile measurements taken (see Methods for details)

and Soligo 2008; Bello et al. 2011b, 2017; Wallduck and Bello 2016). The topography of the surface was recorded to produce three-dimensional (3D) micro-morphological models of the incisions. Micro-morphometric parameters for the engraving marks were assessed and measured at the incisions' midpoint. The profile measurements considered were width of the incision at the surface (WIS), width at the bottom of the incision (WIB), opening angle of the cut (OA), depth (D), and angle of the tool inclination (ATI) during cutting (Bello et al. 2013). Incision profiles were differentiated into (a) 'single-stroke' incisions, obtained by a single tool passage, and (b) incisions obtained by multiple tool passages (Bello et al. 2017). The multiple tool passages can either be visible when observing the incision's profile, in which case (b1) we define these as 'multiple-strokes' incisions; or (b2) the latter passage(s) overlap the previous ones in a way that makes it impossible to differentiate the strokes from the profile shape, and we define these as 'multiple-overlapping-strokes' (Fig. 2). For finer details, observations were also conducted using a scanning electron microscope (SEM), the JEOL IT500. This SEM can produce both back-scattered and spectro-electron images, the latter of which provides a better indication of a surface's topography. Finally, we CT scanned the three batons using an HMX-ST CT 225 System (Metris X-Tek, Tring, UK) to assess their internal structure and the presence of micro-fractures that could be possibly associated with the use of the batons (Bello and Galway-Witham in press). All microscope instruments are housed at the Natural History Museum (London, UK).

The traces observed on the Gough's Cave batons were then compared with those that have been detailed in previous publications of Paleolithic perforated batons (e.g., Chauvet 1910; Glory 1965; Mons 1976; Noiret 1990; Peltier 1992; Menéndez García 1994; Rigaud 2001; Lompre 2003a, 2003b; Clottes and Delporte 2003; Kilgore and Gonthier 2014; Redondo Sanz 2016), as well as a sample of 26 engraved Magdalenian perforated batons that were directly analyzed by one of the authors (CL). This sample includes 18 perforated batons from the western Pyrenees that were studied as part of a PhD thesis (Lucas 2014) and 8 other perforated batons from South-western France specifically selected for the purpose of this study (Table 1). This comparative sample is not fully described in the present paper, but was used as reference for the identification and characterization of the modifications observed on the Gough's Cave batons.

We have not developed any experimental work that could serve as a reference to test different hypotheses about possible

Table 1 Comparative sample analyzed in person and used as a reference for the identification and characterization of modifications observed on the Gough's Cave batons

Site	Studied batons	Museum numbers
Isturitz	10	MAN 74896; MAN 74898; MAN 74903; MAN 84721; MAN 84789; MAN 86704; MAN 86725; MAN unnumbered (3x pieces)
Espalungue	4	MAN 47011; MAN 47179; MAN 49121; MAN 49132
Duruthy	3	Arthous 19.1.22; Arthous unnumbered (2x pieces)
Le Placard	3	MAN PL55041; MAN PL55043; MAN PL55064
Saint-Michel d'Arudy	1	MAN 56388
La Madeleine	1	MAN 3418
Gourdan	1	MAN 47079
La Vache	1	MAN 83365
Lortet	1	MAN 48214
Mas d'Azil	1	MAN 47729
Total	26	

uses of the perforated batons. However, our interpretation of the traces observed on the Gough's Cave batons refer to existing references that have experimentally tested how perforated batons can be modified by specific actions (Table 2).

Results

The three perforated batons from Gough's Cave are made of reindeer antler, clearly recognizable from the density of the compact and cancellous tissues (Fig. 3), as well as the smooth outer surface (with some impressions of blood vessels) still visible on some unmodified parts of the surfaces (Bouchud 1966; MacGregor 1985; Averbouh 2000; Christensen 2004). They are generally well preserved, with only one of them having been considerably broken (NHMUK PA E 7783). While we have not identified typical alterations left by vegetal or animal agents on these three artifacts, the osseous surfaces are of unequal condition, with some areas concealed by dissolution and shedding of the antler surface or adhering encrusted sediment probably due to the circulation of water into the cave.

Description

Perforated baton NHMUK PA E 7783

The maximum length of this baton is 130 mm, although due to ancient breakage at both ends, its original length is unknown. The distal break runs obliquely across the upper branch, which is 25 mm long, and continues beyond the perforation to the base of the other (missing) branch. The end of the upper branch shows a groove plane indicative of sectioning by sawing (Fig. 4Ba), as previously noted by Patricia McComb (1989). The proximal break on the mid-shaft is an irregular tongued break with a long tongue (46 mm), and it is associated with longitudinal cracks running almost the entire length of the shaft, which has a sub-circular cross-section (26 × 22 mm). Two of the longitudinal fractures resulted in the detachment of a small fragment (51 × 11 × 6.5 mm), elongated and sub-triangular, found at least 2.4 m away from the main portion. The baton surface is in places concealed by some shedding of the antler surface that partially altered the lower face of the upper branch, and by spots of encrusted sediment, which are especially dense on the mid-shaft.

The shaft surface has two types of engraving: (a) clusters of superficial striations and (b) deeper lines that spiral around the shaft. (a) The superficial striations appear on four areas of the shaft and are made up of short sub-parallel incisions, generally with an oblique angle to the long axis of the shaft and in one case forming a criss-cross motif (Fig. 4C e–g). These shallow incisions (31 of which were measured using Focus Variation microscopy and associated software) were mainly made by a single tool passage, with only a few cases of multiple tool passages (seven cases of profiles corresponding to double-strokes and one instance of multiple-overlapping-strokes). They are generally narrow (average WIS = 458.0 μm, standard deviation (SD) = 158.0 μm; WIB = 112.0 μm, SD = 54.0 μm) and superficial (average D = 69 μm, SD = 38 μm; Tables 3 and S1). These shallow incisions give an irregular appearance to the surface by forming scratched areas rather than real patterns. They are, in places, overlapped by (b) deeper incisions (Fig. 4C f, h, i). These latter incisions form a band consisting of five to seven sub-parallel lines, more or less continuous, that spiral around the shaft. The band measures 13 to 16 mm in width and the blank spaces between each coil measures between 24 and 30 mm. This pattern was engraved from the base of the baton towards the distal part and ends at the bottom right of the perforation on the upper face. While the incisions are generally continuous, occasional

Table 2 Primary references that were used to interpret the traces observed on the Gough's Cave batons; these test experimentally how perforated batons may have been modified by specific actions

Action	Experiment	Observed use-wear and breaks	References
A strap rubbed through the perforation	Used two wooden perforated batons as catapult shafts in conjunction with a leather strap	Use-wear in Glory's areas 2–3 and 6–7	Glory 1964: 80–82; 1965: 60–62
	Tested the effect of three straps, made of horse hair, tendon and sisal, within a single antler baton perforation	Areas of polishing on the perforation edge	Lompre 2003a: 12–22; 2003b: 24–25
A wooden stick rotated within the perforation	Used two antler perforated batons and two wooden perforated batons as rope making tools (type 'torteirae') to produce a rope made of horse hair and bison wool	Areas of bright polishing throughout the full internal circumference of the perforation	Rigaud 2001: 121–123
A stick of variable material levered within the perforation	Straightened several antler points with perforated batons	None	Leroi-Gourhan 1971
	Straightened several antler points with three antler perforated batons	None	Peltier 1992: 22–26
	Straightened 10 antler points with a single antler perforated baton	None on the perforated batons; compression of the cancellous tissue on the points	Rigaud 2001: 108
	Deliberate breakage of 8 antler perforated batons with a stick levered within the perforation	Breaks were only obtained with a steel stick (10 mm in diameter): this produced distal saw-toothed breaks when the baton was handled by hand and distal oblique breaks were only obtained when the baton was held in a vice	Rigaud 2001: 131–133
	Straightened five antler points with a single antler perforated baton	Superficial *écrasement* and micro-chipping of the perforation edge on the baton; symmetrical compressions on the points	Lompre 2003a: 12–22; 2003b: 20–21
	An antler tine was levered through an antler perforated baton with high force, through the use of a suspended load	Alternate superficial *écrasement* of the perforation edge	Lompre 2003a: 12–22; 2003b: 21–23
	Straightened several antler points with two antler perforated batons	Either superficial *écrasement* or none	Redondo Sanz 2016
A rope pulled through the perforation of a baton	Deliberately broke eight antler perforated batons through use as cable blockers, in conjunction with a sisal rope	Breaks when subjected to a force equivalent to a 10 kg load falling from a height of 2 m	Rigaud 2001: 133–139
	Used an antler perforated baton as a cable blocker	*Écrasements* and micro-striations on the perforation edge	Lompre 2003a: 12–22; 2003 b: 23–24
	Used two antler perforated batons and two wooden perforated batons as cable blockers, in conjunction with a sisal rope	Use-wear when the rope was passed through the perforation, producing alternate areas of polishing across Glory's areas 2–3 and 6–7	Rigaud 2004

interruptions are visible and indications of multiple resumptions of the incisions are evident along the length of the lines. Instances where the incision has been resumed, but does not perfectly match-up with the original incision (i.e., deviations, intersections, crossing, or double parallel lines), and numerous involuntary tool exits (due to a lack of control of the tool sliding on the convexity of the shaft surface), suggest imprecision in the execution of the work (Fig. 4C h and i). Profile analyses show that the main lines were deepened by multiple tool passages, although some incisions created by a single tool passage are also visible. Despite the variability in the way they were produced, the deeper spiraling lines are on average notably wider (average WIS = 686.0 μm, SD = 261.5 μm; WIB = 131.5 μm, SD = 66.0 μm) and deeper (average D = 137.0 μm, SD = 92.0 μm; Tables 3 and S1) than the superficial striations. In the case of multiple-stroke incisions, the ATI values show various combinations on how the tool was held (each stroke produced either by holding the tool with the same inclination, or opposite inclinations; refer to Bello et al. 2013 for details). For both the superficial and the deeper incisions, the opening of the angle is comparable, suggesting that they were probably produced by similar tools. Overall, however,

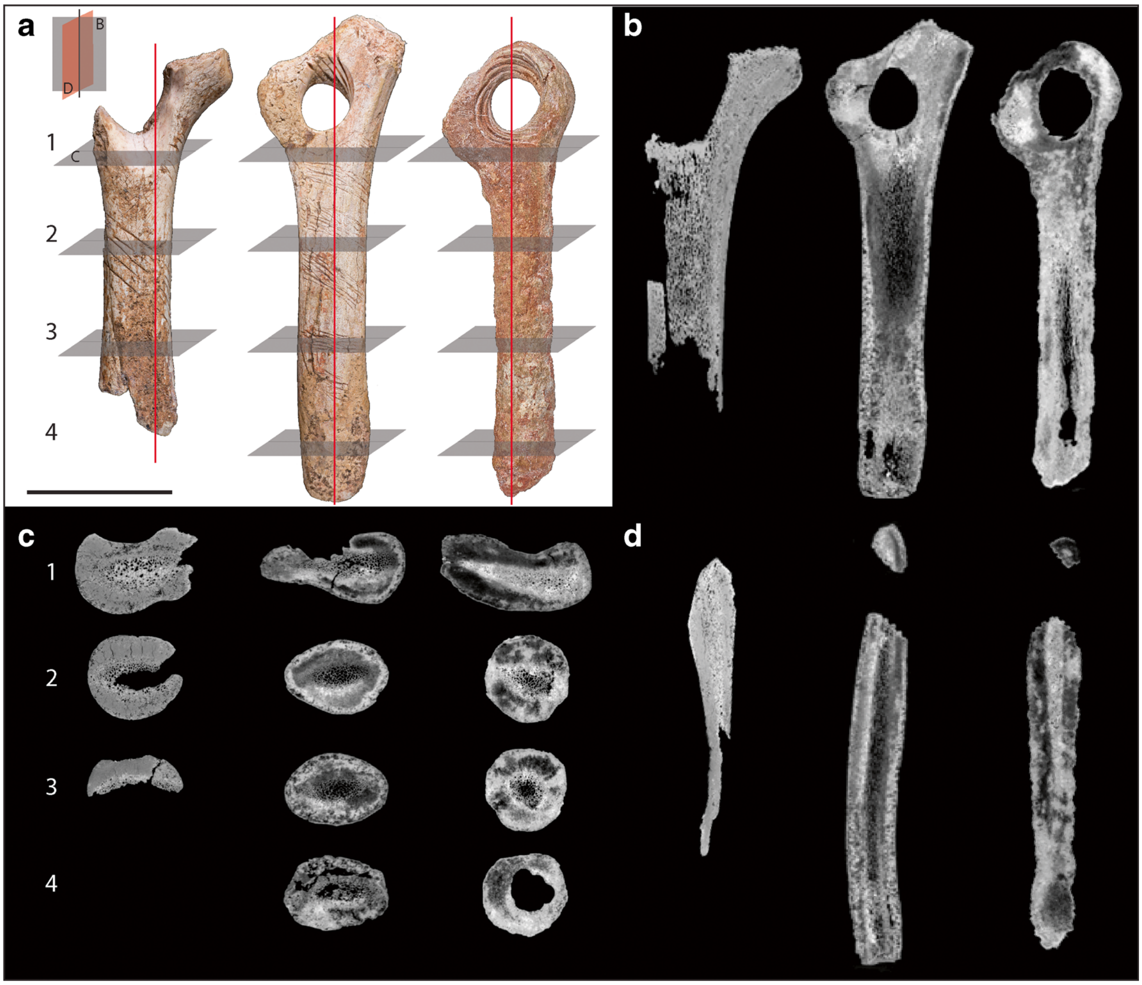


Fig. 3 **A** Photo of the upper faces of the three perforated batons. CT slices of the three perforated batons; **B** parallel to the long axis of the baton (i.e., z-plane); **D** perpendicular to the long axis (i.e., x-plane); and **C** horizontal sections across the shafts (i.e., y-plane). Scale = 50 mm

inconsistencies in the way the deeper and shallower incisions were made suggest a lack of gestural consistency and meticulousness in attempting to produce a regular pattern.

Several polished areas are present on the right side of the shaft (Fig. 4Bb) and at the end of the upper branch (Fig. 4Ba). As the baton is broken, only the lower edge of the perforation remains, upon which are four concave areas, two on either face. Patricia McComb (1989) has described these concavities as having been formed when shaping the perforation. However, these concave areas are similar in appearance to a type of use-wear described as 'écrasement' on other perforated batons (Lompre 2003a: 13; Lompre 2003b: 34). Superficially, the Gough's Cave baton do indeed display regular concavities with a smooth polished aspect that aligns them with the compacted surface of the *écrasements*. Nonetheless, CT data show a loss of compact tissue without evidence of compression, in the absence of brighter band of voxels (pixels) that would have signaled increased density in this area (Fig. 3C, D, and Fig. 4Bd). On both upper and lower faces, the two concave areas are orientated transversally (areas 5 and 8 of Glory's diagram), and longitudinally to the shaft axis (areas 6–7 of Glory's diagram), respectively, with the latter overlapping the former, and therefore produced after. On the upper face, the longitudinal concavity is particularly large, extending over 14 mm in length towards the shaft, with 18 mm in maximum width (Fig. 4D). On the lower face, the transverse concavity (in area 8) has been engraved with at least three curved lines (Fig. 4Dj and k). Obtained by several tool passages, these incisions have a U-shaped profile (corresponding to multiple-overlapping-strokes) and are particularly wide (average WIS = 1.1 mm, SD = 245 mμm; WIB = 280.0 μm, SD = 161.0 μm) and deep (average D = 230.5 μm, SD = 132.6 μm; Tables 3 and S1). These characteristics are suggestive of a strong cutting action (cf. Bello et al. 2009, 2017; Wallduck and Bello 2018), while the tool is held almost perpendicular to the antler surface (as reflected by the ATI values). This technique was probably intended to produce deep, visible and well-formed engraved incisions. The ends of these incisions have been partially erased by the longitudinal concavity (Fig. 4D).

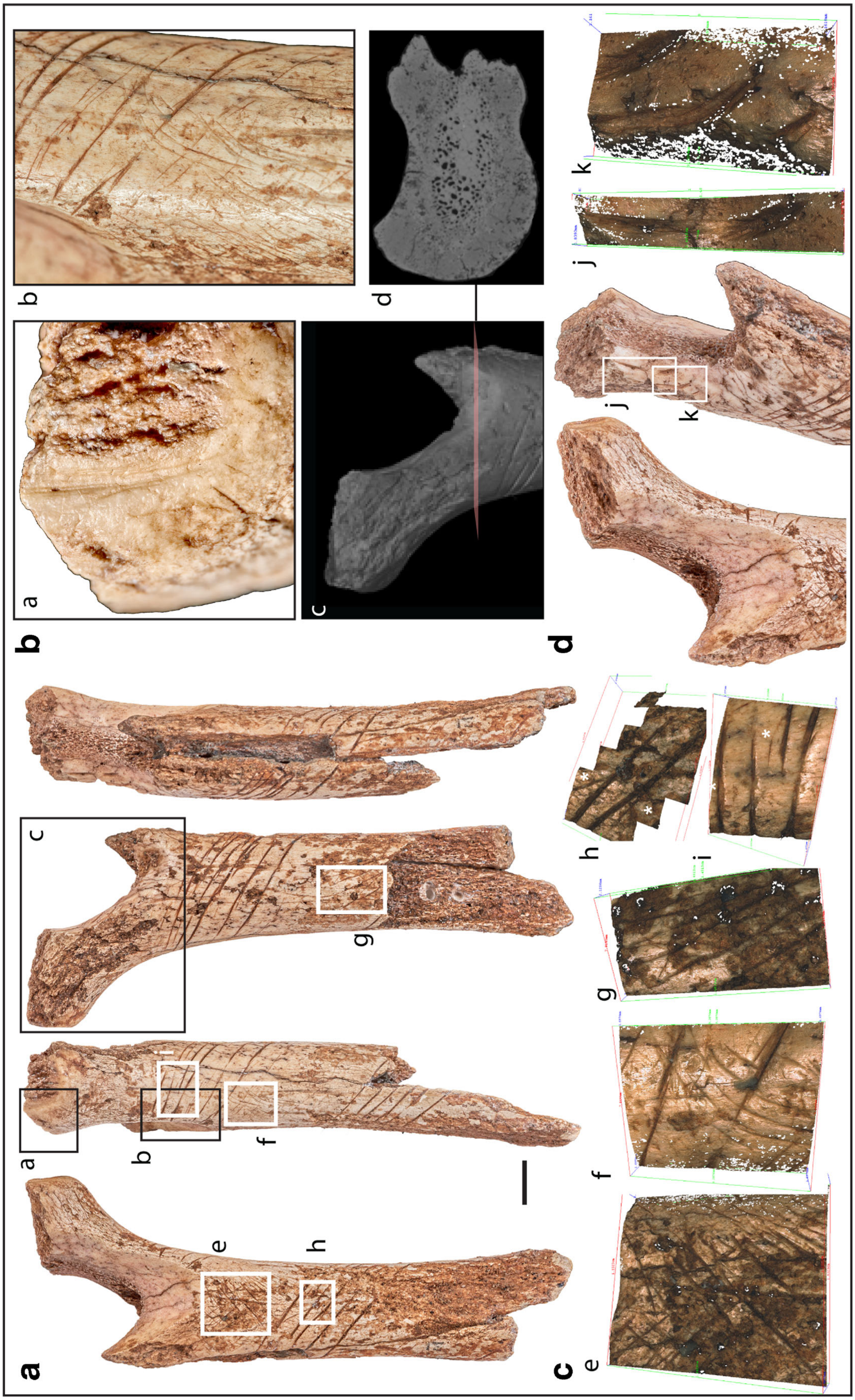


Fig. 4 Perforated baton NHMUK PA E 7783 from Gough's Cave: **A** photos of the upper face, right side, lower face, and left side of baton. Scale = 10 mm. **B** (a) Groove plane produced by sawing of the upper branch of the baton. (b) Polishing on the right side of the shaft. (c) CT rendering and (d) CT slice of the distal portion of the baton. **C** Alicona images detailing: (e and g) superficial striations; (f) superficial striations overlapped by deeper incisions; (h and i) examples of deeper incisions, which spiral around the shaft. It is possible to observe several resumptions and involuntary tool exits (indicated by *). **D** Photos of concave wear around the perforation on the upper and lower faces of the baton. (j and k) Alicona images detailing the incisions on the lateral concavity on the lower face of the baton (white areas on the Alicona images are indicative of error in reproducing surfaces with a slope angle > 80°)

Table 3 Profile analyses of the incisions on the three perforated batons from Gough's Cave according to the incisions' locations. Profile parameters taken: width of the incision at the surface (WIS), width at the bottom of the incision (WIB), opening angle of the cut (OA), depth (D), and angle of the tool inclination (ATI) during cutting. Number (No) of incisions measured, mean values, standard deviations (SD), minimum (Min) and maximum (Max) values

Perforated Baton	Location	Type of incision	No		WIS (μm)	WIB (μm)	OA (°)	D (μm)
NHM PV E 7783	Shaft	*Deep incisions*						
	Upper face	Single stroke	12	Mean =	334.33	111.46	126.32	74.62
				SD =	133.33	58.42	28.20	68.44
				Min =	106.12	36.01	56.67	15.58
				Max =	494.96	233.95	159.32	246.36
		Multiple strokes	31	Mean =	814.92	109.13	124.90	129.15
				SD =	197.36	42.37	21.97	75.68
				Min =	513.48	50.06	60.97	33.08
				Max =	1232.89	207.83	154.16	376.11
		Multiple-overlapping strokes	10	Mean =	710.51	225.39	102.20	234.39
				SD =	145.89	54.50	25.34	90.90
				Min =	535.05	152.6	66.38	92.33
				Max =	1036.18	335.33	139.34	356.96
	Lower face	Single stroke	3	Mean =	291.15	86.17	155.47	24.54
				SD =	123.22	24.97	7.22	10.90
				Min =	217.40	57.41	147.47	15.98
				Max =	433.40	102.32	161.50	36.82
		Multiple strokes	8	Mean =	519.87	95.32	134.76	66.52
				SD =	173.92	71.65	26.05	39.54
				Min =	362.63	39.12	78.80	30.71
				Max =	792.23	211.35	157.93	136.59
		Multiple-overlapping strokes	0					
		Shallow incisions						
	Upper and lower faces	Single stroke	15	Mean =	409.76	128.41	136.35	70.11
				SD =	112.05	51.03	14.63	31.09
				Min =	218.55	59.46	102.58	19.33
				Max =	613.68	243.71	156.95	138.60
		Multiple strokes	4	Mean =	567.59	91.2375	126.24	90.19
				SD =	129.44	41.66	12.10	52.87
				Min =	455.49	51.63	110.65	29.13
				Max =	679.69	137.4	136.97	157.44
		Multiple-overlapping strokes	1		749.3	170.52	142.59	131.45
	Perforation	Multiple-overlapping strokes	4	Mean =	247.81	136.81	14.62	132.29
				SD =	908.25	240.24	114.39	108.64
				Min =	1446.98	549.5	146.39	427.98
				Max =	247.81	136.81	14.62	132.29
NHM PV E 7782	Shaft							
	Upper face	Single stroke	25	Mean =	348.77	121.85	147.23	41.38
				SD =	85.55	52.36	16.13	18.86
				Min =	192.67	52.79	87.57	13.01
				Max =	525.07	262.69	164.80	99.78
		Multiple strokes	30	Mean =	713.87	89.19	144.55	65.82
				SD =	258.80	39.45	16.94	36.25
				Min =	336.87	35.01	89.49	9.26
				Max =	1080.38	161.19	172.79	147.46
		Multiple-overlapping strokes	24	Mean =	644.83	190.36	134.27	102.62

Table 3 (continued)

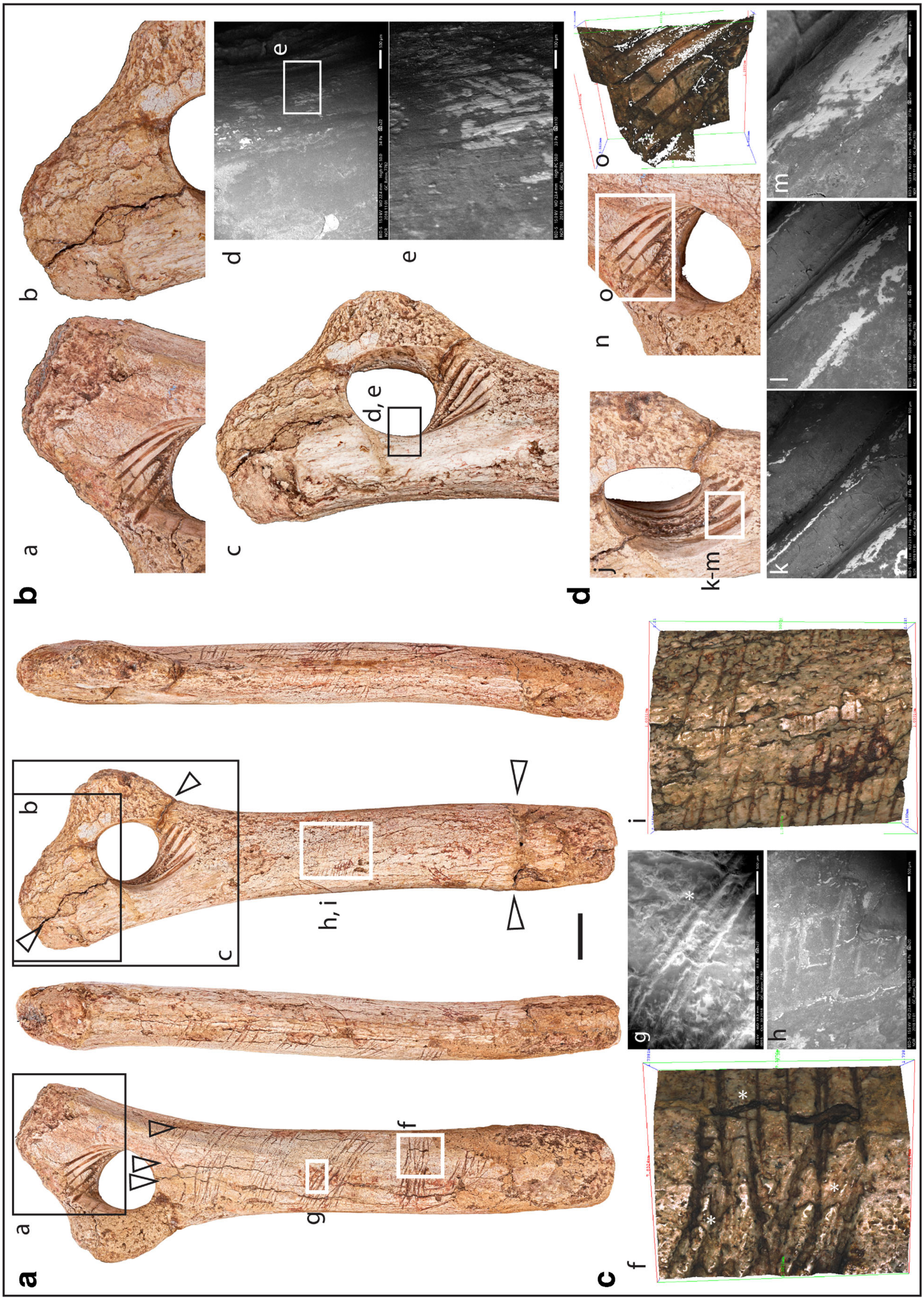
Perforated Baton	Location	Type of incision	No		WIS (μm)	WIB (μm)	OA (°)	D (μm)
				SD =	252.68	57.84	12.27	49.94
				Min =	409.21	93.46	104.51	55.58
				Max =	1354.79	283.28	156.74	250.33
	Lower face	Single stroke	19	Mean =	295.05	91.81	135.86	51.13
				SD =	76.07	29.30	15.59	19.08
				Min =	147.05	42.82	105.27	7.40
				Max =	420.27	178.69	165.39	85.66
	Perforation	Multiple-overlapping strokes	8	Mean =	83.56	623.10	1382.12	477.97
				SD =	18.07	217.98	397.85	83.25
				Min =	53.97	281.35	1019.40	367.04
				Max =	112.96	829.98	2122.28	591.69
NHM UNREG 4196	Perforation	Multiple-overlapping strokes	9	Mean =	1554.14	504.45	98.50	567.98
				SD =	430.56	175.34	23.98	270.85
				Min =	858.72	282.78	70.57	89.54
				Max =	2408.73	843.80	151.03	940.18

Perforated baton NHMUK PA E 7782

This artifact measures 170 mm in length. The distal part of the baton has a large almost circular perforation (17 × 16 mm in diameter), a short lower branch (16 mm long), and a longer upper branch (28 mm long). The end of the upper branch shows numerous, small invasive removal scars (Fig. 5B a and b), which indicate sectioning by peripheral sharp percussion (cf. removal of antler shavings by percussion with a sharp tool). The 131-mm-long shaft has an ovate cross-section (25 × 17 mm; Fig. 3C). Despite being complete, this baton is weakened by a number of cracks. On the upper face, there are three sinuous cracks radiating from the perforation (towards both distal branches and the shaft), that cut across the entire thickness of the baton as visible on CT scans (Fig. 3B). These cracks are associated with numerous superficial cracks running longitudinally along the shaft. On the lower face, there are two deep cracks, affecting most of the thickness of the baton. The crack towards the perforation runs obliquely across the upper branch and across the base of the lower branch. The second crack runs transversally across the shaft, ~25 mm from its base. While there is little encrusted sediment, the baton surface is considerably altered by dissolution and shedding of the antler surface. This has entirely concealed the lower branch and the base of the shaft and damaged important parts of the lower face on the shaft and the upper branch. The base of the shaft is also partially covered by conservation mastic.

The shaft surface has been engraved on both faces. On the upper face, there are six bands consisting of a dense cluster of short oblique incisions that partly intersect (Fig. 5A and C f and g). The bands, measuring 5 to 10 mm wide, are separated by blank spaces of 7 to 16 mm wide. They run obliquely across the shaft surface from side to side, with an orientation top-left to bottom-right. The top band is shorter, however, and ends at the right of the perforation on the upper face, where it is intersected by a few incisions that curve at a ~60° angle to the band. The resulting pattern gives the impression of spiraling around the shaft, though in fact each band of incisions ends on the sides. The incisions (79 of which were measured using Focus Variation microscopy and associated software, S1) are very irregular and have been produced by single or multiple tool passages. Overall, they are slightly narrower (average WIS = 577.0 μm, SD = 267.0 μm; WIB = 130.0 μm, SD = 64.5 μm) and shallower (average D = 69.0 μm, SD = 44.0 μm; Tables 3 and S1) than the deep incisions present on the shaft of NHMUK PA E 7783. When multiple-stroke incisions are present, the ATI values indicate that the tool was held at different inclinations, with no consistency. Overall, the engraving procedure that consists of the accumulation of irregular, short intersecting incisions gives the general pattern a crude appearance (Fig. 5Cf and g). On the lower face, there is only one large band formed of numerous transverse incisions. This cluster of incisions is less well preserved, but generally appears more homogeneous (Fig. 5C h and i) as the incisions (19 of which were measured using Focus Variation microscopy and associated software) were produced by single tool passages. As a result, these incisions are overall narrower (average WIS = 595.0 μm, SD = 76.0 μm; WIB = 92.0 μm, SD = 29.0 μm) and slightly shallower (average D = 51.0 μm, SD = 19.0 μm; Tables 3 and S1) than the engraving on the upper face of the baton.

A clear polished area is notable to the left of the perforation on the lower face of the baton (Fig. 5B c). Despite its smooth


a
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◀ **Fig. 5** Perforated baton NHMUK PA E 7782 from Gough's Cave. **A** Photos of the upper face, right side, lower face, and left side of the baton. The white triangles indicate the location of the main cracks. Scale = 10 mm. **B** Detailed photos of the (a) upper and (b) lower face of the upper branch showing numerous, small invasive removal scars, which indicate sectioning by peripheral sharp percussion. (c) Photo of polished area on the left of the perforation on the lower face of the baton and (d and e) SEM images of the polish area with series of micro-striations closer to the edge of the perforation. **C** Alicona (f and i) and SEM (g and h) images detailing: (f and g) examples of deep irregular incisions, with evidence of resumption and involuntary tool exits (indicated by *). (h and i) Examples of shallower and more regular incisions on the lower face of the baton, interrupted by erosion of the cortical surface. **D** Photos of concave wear on the perforation on the (j) lower and (n) upper faces of the baton. (k–m) SEM images of the engraving within the perforation showing polishing and micro-striations on the ridges between engravings. (o) Alicona image of the engraving within the perforation on the upper face of the baton (white areas on the Alicona images are indicative of error in reproducing surfaces with a slope angle > 80°)

appearance, a series of micro-striations are visible on the polished area, towards the edge of the perforation (Fig. 5B d and e). The perforation has two alternate areas of concave wear; one on the upper face, located on the upper edge of the perforation (areas 2–3), and one on the lower face, located on the lower edge (areas 6–7). These concavities are, respectively, about 7 and 11 mm long and are 18–19 mm wide. Similarly to baton NHMUK PA E 7783, CT scans suggest a conspicuous loss of compact bone, particularly evident where the surface has been engraved (Fig. 3C and D). The surfaces of the concave areas between the engravings are clearly polished, and a few micro-striations perpendicular to the engravings are also visible at higher magnification (Fig. 5D k–m). Both concavities have been engraved with five deep curved lines (Fig. 5D), which cut through the compact tissue (Figs. 3C and 5D). These incisions follow the curvature of the concave areas and were traced from the internal portion of the perforation edge towards its external part, where the lines end at the outline of the concave wear. The engraved lines are very regular (Fig. 5D), with a spacing of 1 or 2 mm between each line. Each incision was produced by several overlapping tool passages, resulting in wide (average WIS = 1.4 mm, SD = 398.0 μm; WIB = 478.0 μm, SD = 83.0 μm) and deep (average D = 623.0 μm, SD = 217.0 μm; Tables 3 and S1) incisions with a U-shaped profile. Despite the difficult access and curved surface of the perforation edge, these engravings have only a few irregularities, and lack obvious involuntary tool exits, suggesting they were carefully and skillfully produced. This clearly contrasts with the irregularities of the engravings on the shaft.

Perforated baton NHMUK PV UNREG 4196

The third baton measures 152 mm in length and its surface is concealed in many places by adhering encrusted sediment. As molds and casts of this baton were made, there are also small remnants of white casting material in the cracks and hollows presents on the baton surface. The distal part is composed of a large ovate perforation (16 × 18 mm), a short lower branch (18 mm long), and a shorter upper branch (12 mm long). The upper branch has been rounded by intense transversal scraping, leaving clear scraping striations on its distal end (Fig. 6B a and b). The right side of the distal part, just below the upper branch, has been modified, probably by percussion with a sharp tool, which produced an indentation (~ 4 mm deep) above a thinned area with scraping striations (Fig. 6B a and c). The 122-mm-long shaft has a circular cross-section (20 × 20 mm). Unlike the shafts of batons NHMUK PA E 7783 and 7782, none of the natural outer surface of the antler remains, and the compact tissue has been altered by numerous depressions, which gives the shaft an irregular appearance (Figs. 3 and 6C d-f). These modifications are not explained by the taphonomy of the site, as no other faunal remains found in the same archeological context in area I display the same poor state of preservation (Bello et al. 2015). They may be due to the making or use of the baton, although we were not able to identify any clear working traces or use-wear. The proximal end shows a single beveled shape, but no further associated working traces can be seen, making it impossible to ascertain whether this is the original base of the baton. The thickness of the compact tissue compared to the thin amount of cancellous tissue (< 4 mm thick) suggests that the portion of antler used for this baton was close to the base of the antler (Fig. 3C). This particularly dense antler baton only shows short sinuous cracks radiating from the perforation in the direction of the shaft, the lower branch and the upper branch. These are superficial and do not affect the entire thickness of the compact tissue (unlike baton NHMUK PA E 7782; Fig. 3B).

The perforation has been subjected to important distortions. It is possible to recognize four areas of concave wear, two on the upper face in areas 3 and 7 of Glory's diagram, and two on the lower face, in areas 2 and 6 of Glory's diagram. All four concavities have been engraved with four or five curved lines, which extend around most of the circumference of the perforation (Fig. 6D). These incisions were made by multiple overlapping tool passages from the internal part of the perforation edge toward its external portion. Similar to the other batons from Gough's Cave, these incisions are generally wide (average WIS = 1.5 mm, SD = 430.5 μm; WIB = 504.5 μm, SD = 175.0 μm) and deep (average D = 568.0 μm, SD = 271.0 μm; Tables 3 and S1), with a U-shaped profile. They are regularly spaced, with ~ 1 mm between each line. The almost complete lack of irregularities in the drawing of their curves and the absence of obvious involuntary tool exits, are, once again, suggestive of careful engraving. The ends of the curved lines, which extend toward the upper branch, have been erased by the later modification of the upper branch.

Chaîne opératoire

All batons from Gough's Cave have been affected by extended use-wear, re-working, and breakage, which have altered the original surface of the batons, leaving only few visible traces of the first phases of the *chaîne opératoire* (debitage and shaping; Fig. 7).

Debitage and shaping

The sectioning actions were only identified on two branches: the upper branch of NHMUK PA E 7783, sectioned by sawing (Fig. 4Ba), and the upper branch of NHMUK PA E 7782, sectioned by peripheral sharp percussion (Fig. 5B a and b). In both cases, the sectioning was performed in order to obtain a short upper branch (25–28 mm long), while the lower branches are even shorter (16–18 mm long; Table 4). All batons have been perforated at the confluence of the lower and upper branches; however, we have been unable to identify the specifics of the drilling actions (tool used, technique, or direction of drilling) due to later extensive modifications of this portion. The circular or ovate perforations of the three batons are large (~ 16–18 mm in diameter).

Engraving on the shaft

Damage of the shaft of baton NHMUK PV UNREG 4196 has obscured any details that may have been present previously. The shafts of batons NHMUK PA E 7783 and NHMUK PV E 7782, however, show clear evidence of engraving. Some areas of baton NHMUK PA E 7783 were initially scratched by shallow incisions made by a single tool passage. These were overlapped by several bands of incisions, engraved obliquely across the shaft. Similar large oblique bands of incisions are also present on the upper face of NHMUK PA E 7782 and the general organization of the pattern engraved on both shafts is also comparable. Despite the similarities in shape and orientation of these engraved bands, they were obtained by different engraving procedures: the engravings on NHMUK PA E 7782 were produced by an accumulation of numerous short intersecting incisions, while NHMUK PA E 7783 shows a more linear engraving procedure, with long parallel incisions that spiral around the shaft. On both batons the resulting engraved bands appear crudely made due to numerous involuntary tool exits and variability in the width and depth of the incisions (Figs. 4C and 5C).

Use

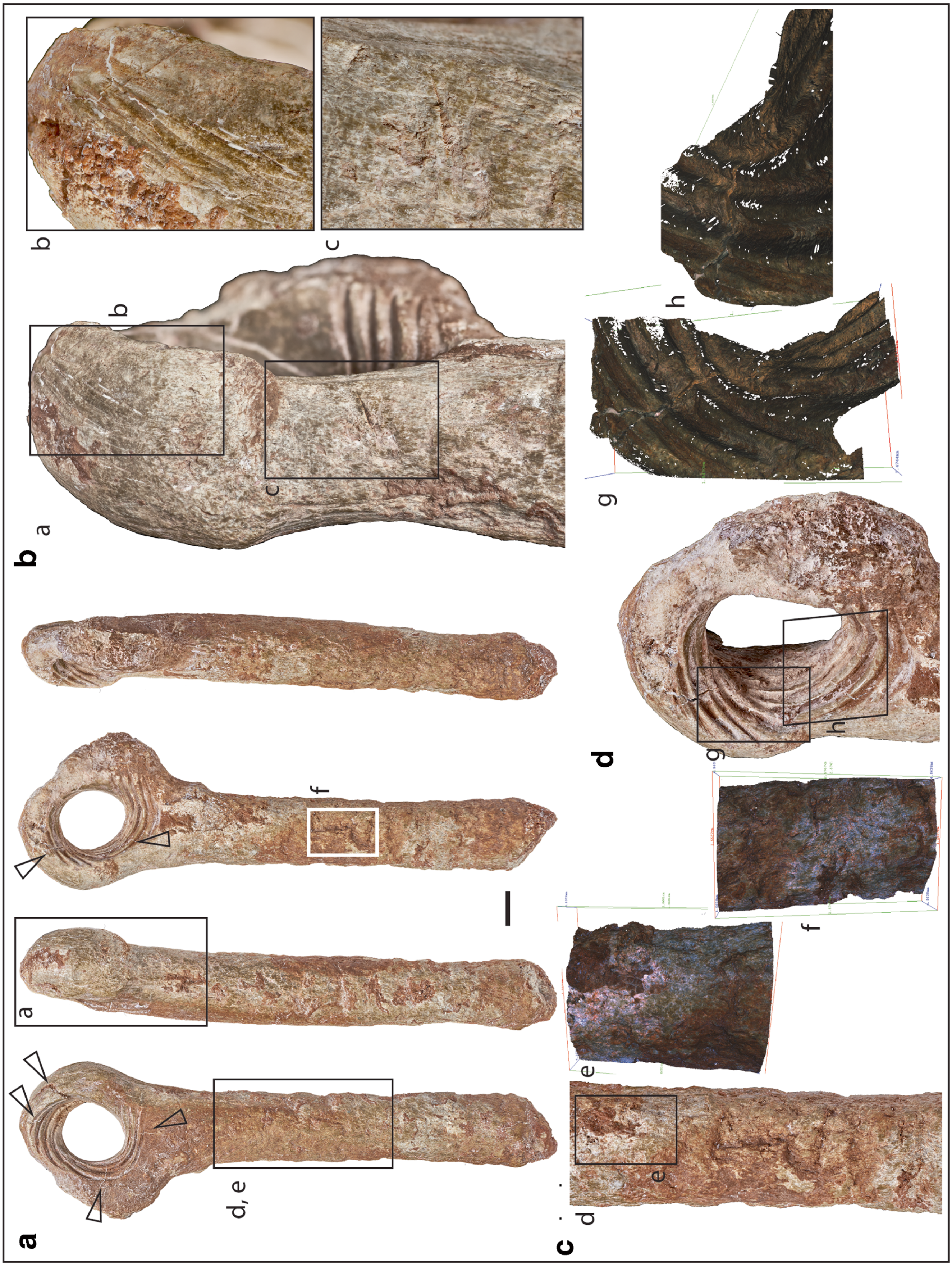
The use of the three batons generated smooth concave areas on the edges of the perforations (Fig. 8), which are macroscopically similar to a type of use-wear defined as

Fig. 6 Perforated baton NHMUK PV UNREG 4196 from Gough's Cave. ▶ **A** Photos of the upper face, right side, lower face, and left side of the baton. The white triangles indicate the location of the main cracks. Scale = 10 mm. **B** Photos detailing (a) the distal end of the right side of the baton showing (b) intense transversal scraping and (c) scraping below the indentation, probably produced by a sharp tool. **C** (d) Photo and (e and f) alicona images detailing the irregular surface of the shaft of the baton. **D** Photo of the distal end of the baton and (g and h) Alicona images detailing the incisions within the perforation of the baton (white areas on the Alicona images are indicative of error in reproducing surfaces with a slope angle > 80°)

'*écrasement*' by Aliette Lompre (2003a: 13; Lompre 2003b: 34). CT analysis of the three batons from Gough's Cave shows that the concavities correspond to a reduction of antler tissue (Fig. 9). The formation of the concavities can be explained by compression of the compact tissue, and/or by the loss of compact tissue that has been worn away. Despite the smooth appearance of the antler surface within the concavity, there is no indication that this was caused by a compression of the compact bone, in the absence of a band of brighter (i.e., denser) voxels following the outline of the concave area on the CT slices (Fig. 9). The visually dense appearance of the concavity may instead be the result of polishing the superficial antler fibers. It is likely that the concavities were produced via some kind of erosion, possibly a recurrent friction of the antler surface against material passing through the perforation, causing an ablation of the compact tissue. The areas of concave wear are particularly large, measuring up to 14 mm in length and 18–19 mm in width. When the entire perforation has been preserved, the worn areas are organized in a typical alternate pattern, where each concavity on the upper edge of the perforation (areas 2–3) corresponds to a concavity on the lower edge of the perforation (areas 6–7) on the opposite face (Fig. 8). They form a simple alternate pattern on baton NHMUK PA E 7782, with one concavity on each face, whereas on NHMUK PV UNREG 4196, they form a double alternate pattern, with two diagonally opposite concavities on either face. It is uncertain whether an alternate organization was present on NHMUK PA E 7783, for which only the lower edge of the perforation is preserved. A clear polished area with micro-striations toward the edge of the perforation has also been observed for baton NHMUK PA E 7782 (Fig. 5B and D). Further evidence of the use or handling of the batons is suggested by polished areas on the distal part and on the shaft of NHMUK PA E 7783 (Figs. 4B and 5B; for 'handling' of object refer to d'Errico 1993).

Re-working

After their first use(s), all three batons were re-worked by engraving four or five curved lines on each worn area on the edge of the perforation (Fig. 8). These curved lines are engraved from the internal edge of the perforation towards the outer edge of the concavities. They were produced by several



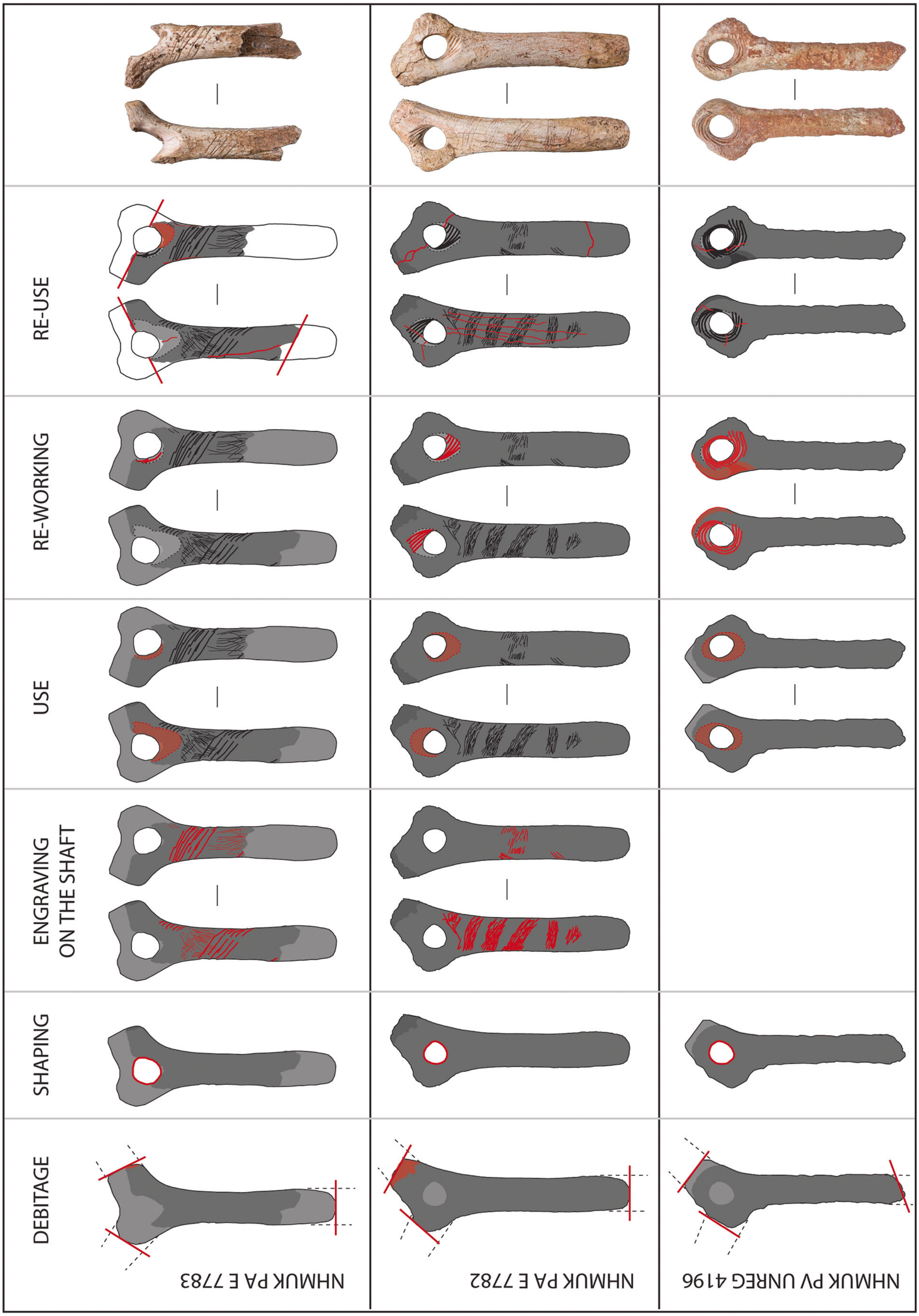


Fig. 7 Schematic representation of the *chaîne opératoire* of making and use of the three perforated batons from Gough's Cave

Table 4 Main dimensions (mm) of the perforated batons from Gough's Cave and compared to the average dimensions of 87 Magdalenian perforated batons from south-western France given by Lompre 2003b

	NHMUK PA E 7783	NHMUK PA E 7782	NHMUK PV UNREG 4196	Batons' average dimensions (Lompre 2003b)
Maximum length	–	170	152[a]	196
Perforation diameter	–	17 × 16	18 × 16	18.3 × 22.7
Perforation shape	–	Circular	ovate	–
Upper branch length	25	28	12[a]	–
Lower branch length	–	16	18	–
Shaft length	–	131	122	133
Shaft width	26	25	20	23.1
Shaft thickness	22	17	20	18
Shaft cross-section shape	sub-circular	Ovate	circular	–
Base type	–	unmodified	beveled?	–

[a] After considerable re-working

tool passages, creating deep and wide incisions, with only minimal irregularities in the drawing of their curves. This uniform pattern suggests good control of the tool. NHMUK PV UNREG 4196 was further re-worked, by re-shaping its distal part; an indentation was created by considerable thinning of the right side of the baton, and the upper branch was shortened to only 12 mm in length (Fig. 6B). This re-working obliterated the ends of the curved lines that were engraved on the perforation edge.

Fig. 8 Distal parts of the three perforated batons from Gough's Cave: photos of the upper face, lower face, and oblique view showing the modifications around the perforation for each baton. Scale = 10 mm

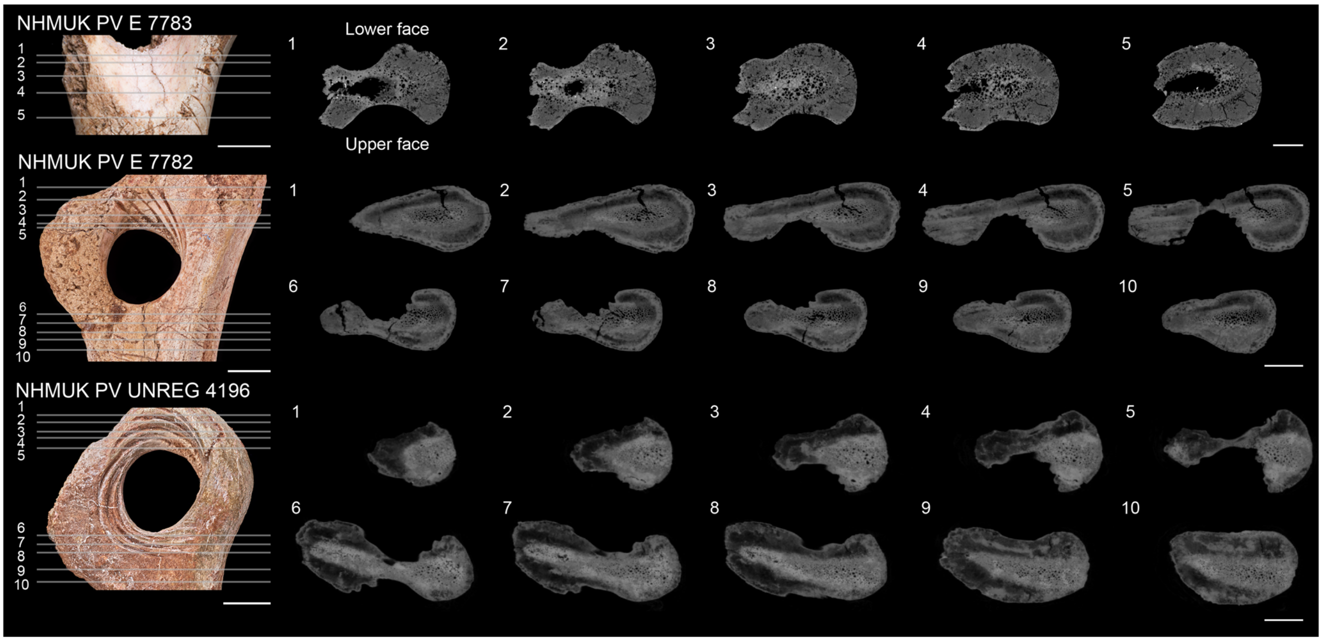


Fig. 9 Photos of the upper surfaces of the three batons from Gough's Cave and sequential CT slices of the concave wear. The orientation of the slices (indicated by the 'lower face' and 'upper face' labels) is consistent for all batons. Scales = 10 mm

Re-use

Following the production of the engravings on the edges of the perforations, the re-use of the batons is evidenced by the formation of additional wear and breakages. An additional longitudinal concave wear is visible on the lower face of NHMUK PA E 7783 altering the ends of the curved lines engraved on the previously formed transverse concavity (Fig. 8A). All three batons also show cracks and breaks. The organization of the fractures is remarkably similar on batons NHMUK PA E 7783 and NMH PV E 7782, both showing an oblique distal fracture (break or deep crack running across the middle of the upper branch to the base of the lower branch), associated with a transverse fracture towards the base of the shaft (break or deep crack) and a number of longitudinal cracks along the mid-shaft. Baton NHMUK PV UNREG 4196, made of particularly dense antler, only shows short cracks radiating from the perforation, and similar radiating cracks are also visible on the upper face of baton NHMUK PA E 7782 (Fig. 3B). Ultimately, all three batons were abandoned having been broken or severely weakened by cracks, and therefore were no longer usable.

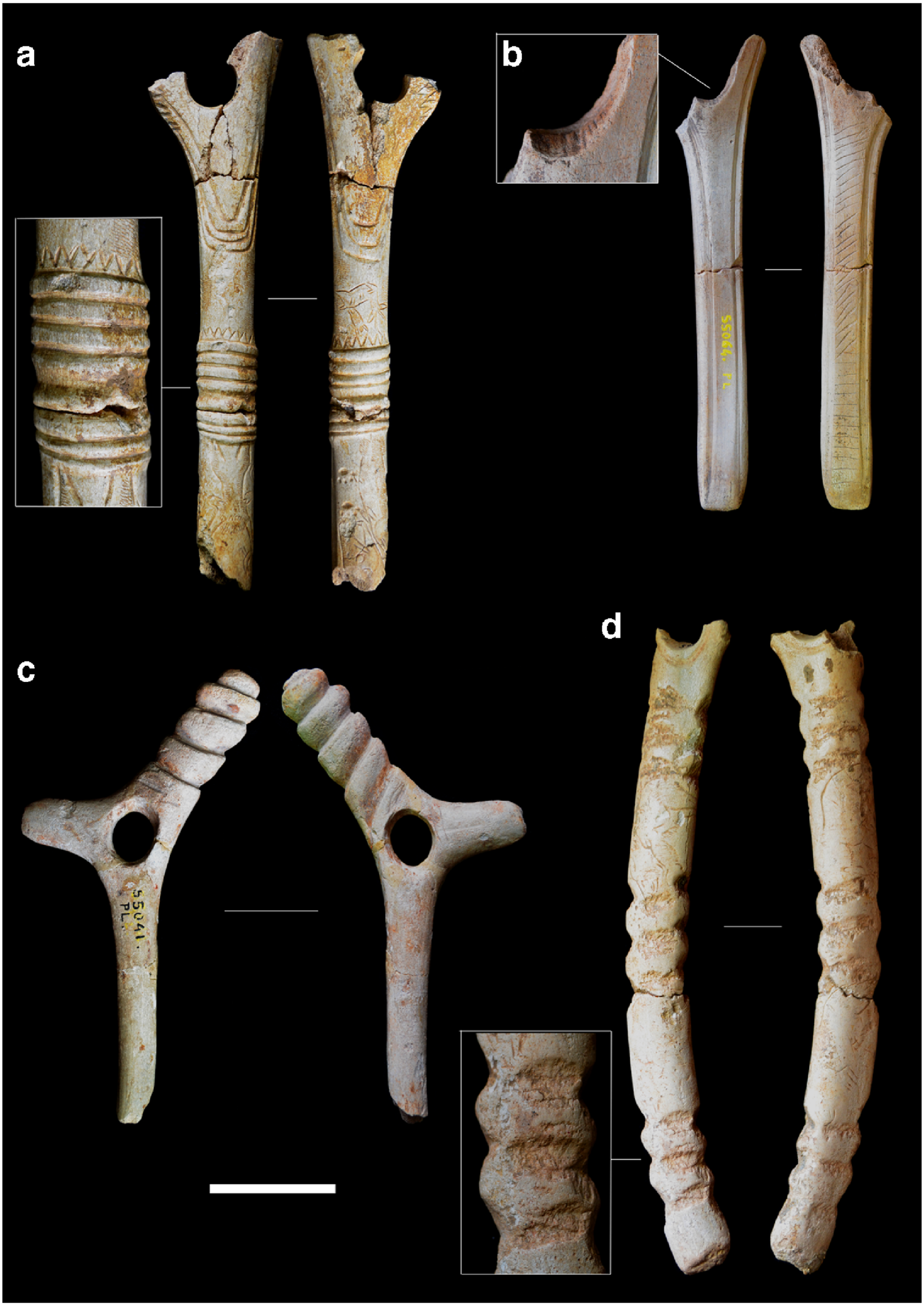
Discussion

The three perforated batons from Gough's Cave are strikingly similar to one another in their overall shape, dimensions (Table 4), engraving designs, and *chaînes opératoires* (Fig. 7). These resemblances suggest that they were produced by the same group of people, and probably within a short period of time. They are the only perforated batons known from Britain, and although they show extensive use resulting in a rich combination of functional features, they have comparable features to other Magdalenian batons from across Europe.

From a typological perspective, the Gough's Cave batons correspond to the most common type of perforated baton; 'baton with a single perforation and two short diverging branches' (Peltier 1992). There is huge variation in the dimensions of Paleolithic perforated batons (45 to 440 mm long; Peltier 1992), and while the two more complete batons from Gough's Cave are slightly shorter than the average for some Magdalenian collections from south-west France (152 and 170 mm in length compared to 196 mm; Lompre 2003b), their perforations (16–18 mm) and the maximum width (20–26 mm) and thickness (17–22 mm) of their shafts perfectly align with the main range of dimensions reported in the same study (Lompre 2003b). Moreover, the sectioning of the distal branches by sawing and peripheral sharp percussion on the Gough's Cave batons fits with the usual debitage procedures on perforated batons from Europe (Peltier 1992).

The use-wear and fractures on the Gough's Cave batons are also similar to those observed on perforated batons from Europe. In particular, the presence of alternate concave wear

Fig. 10 Examples of Magdalenian perforated batons interpreted to have been possibly used with ropes, housed at the Musée d'Archéologie Nationale (Saint-Germain-en-Laye, France). **A** Baton MAN 47079 from Gourdan Cave (Pyrenees, France); **B** Baton MAN PL 55064 from Le Placard Cave (Charente, France); **C** Baton MAN PL 55041 from Le Placard Cave (Charente, France); **D** 'Bâton aux ours' MAN 83365 from La Vache Cave (Pyrenees, France). Scale = 50 mm. Photographs C. Lucas


a
b
55064. PL
c
55041. PL.
d

surrounding the perforation is the most frequent form of use-wear pattern. These indicate that the artifacts were not used in simple suspension, where a material would only wrap around the distal edges of the perforation, or where a stick is rotated within the perforation, which generate use-wear around the full circumference of the internal portion of the perforation (Rigaud 2001: 123). Clearly the objects had a practical function, as the similar concave wear across each face of the batons must have been produced by an elongated object passing through the perforation (see notably experimental results from Lompre 2003a, 2003b; Rigaud 2004). Hence, we can reject earlier hypotheses that suggested these tools served purely symbolic functions (e.g., *bâton de commandement*). While no systematic measurements of concave wear have been undertaken thus far, those affecting the Gough's Cave batons, which are up to 14 mm long and 18–19 mm wide, appear larger compared to illustrations of other batons in previous studies (Glory 1964, 1965; Mons 1976; Rigaud 2001; Lompre 2003a). In addition to their relatively large areas of wear, two of the batons (NHMUK PA E 7783 and NHMUK PV UNREG 4196) show evidence of more than one concavity on each face. This evidence and the conspicuous loss of bone associated with the concave wear (Fig. 8) could support an interpretation of significant use.

While experiments have demonstrated that perforated batons made of fresh (sensu *lato*) antler would only break under very high force (a strength equivalent to the fall of a 10-kg load from a height of 2 m under the traction of a rope; Rigaud 2001), fractures are nonetheless common on perforated batons throughout the Paleolithic (Lompre 2003a; Rigaud 2001, 2004). In particular, André Rigaud estimated that 70% of batons show signs of breakage that could be related to use, generally in the form of oblique breaks across the perforation (e.g., MAN PL 55064 from Le Placard and MAN 47079 from Gourdan Cave; Rigaud 2001) (Fig. 10 a, b). Significantly less common (~ 8% of perforated batons; Rigaud 2001) are cases of double fractures, where possibly simultaneous breaks are found both across the perforation as well as the shaft, which is the case for two of the Gough's Cave batons (NHMUK PV 7783 and NHMUK PA E 7782). For both of these batons, the double fractures are similar in that they both have the typical oblique fracture that runs through the perforation, across the middle of the upper branch to the base of the lower branch, a transverse fracture towards the base of the shaft, and longitudinal cracks along the mid-shaft in between the two main fractures. The marked similarity in breakages between these two batons emphasizes the likelihood that they shared the same function and were used in the same manner. This function probably required the application of considerable force to both ends of the batons, deforming their overall shape, until they eventually broke. Given how resistant to breakage antlers are under experimental conditions (Rigaud 2001; Lompre 2003a, 2003b), the Gough's Cave batons could not have been held by hand given the substantial force that must have been applied to them. By extension, we must consider that the batons were instead just one part in a more complex system that could support this force (Rigaud 2001). Crucially, this discounts the majority of functional hypotheses of perforated batons that have been thus far proposed, including as a spearhead straightener or a catapult shaft.

Fig. 11 Other examples of Magdalenian perforated batons housed at the ▶ Musée d'Archéologie Nationale (Saint-Germain-en-Laye, France). **A** Baton MAN 3418 from La Madeleine rock-shelter (Dordogne, France); **B** Baton MAN 47729 from Mas d'Azil (Pyrenees, France); **C** Baton MAN 48214 from Lortet Cave (Pyrenees, France). Scale = 50 mm. Photographs C. Lucas

Of particular interest are the engravings of curved lines on the perforation edges. These were produced after a first period of use of the Gough's Cave batons, as the engravings start within the perforations and extend into the concave wear. Only a few examples of engravings within the perforations of batons have thus far been identified. Similar engraved curved lines have been documented on perforated batons from Swabian Jura (Germany), which were excavated from Aurignacian levels at Hohle Fels (Conard and Malina 2016) and Geiβenklosterle (Noiret 1990). In particular, these batons have a similar number of deep, curved lines within the perforation, though the Swabian Jura batons are typologically different (they are made from an ivory rod and are multi-perforated, with each hole considerably smaller in diameter than the perforations of the Gough's Cave batons). The (possibly Magdalenian) bone baton SOL AA.5 from La Roche de Solutré (Bourgogne, France; Joconde database) has a single perforation and is therefore more similar to Gough's Cave batons than the ones from Swabian Jura, though the curved incisions on the edge of the perforation of SOL AA.5 are generally thinner and more numerous. A slightly different screw thread like pattern (with circular grooves orientated along the perforation edges) has been noted on T-shaped antler batons from the Aurignacian of Dordogne (Blanchard I, La Souquette, Castanet, Le Poisson; Peyrony 1932, 1935) and the Upper Magdalenian antler baton from Loubressac Cave in the same area (Leclerc and Pradel 1948). Additionally, we have identified parallel dashes engraved on the lower edge of the perforation of the Magdalenian antler baton MAN PL 55064 from Le Placard Cave (Charente, France; Fig. 10b), which were partly obliterated by later concave wear. Despite their scarcity, the location of engravings on the edges of the perforation, which is the active part of the batons that was subjected to considerable use-wear, is a significant clue to indicate their possible functional role. The sequence of 'use, engraving, and re-use' identified in the *chaîne opératoire* of the Gough's Cave batons, and the alignment of the engravings with the concave wear from earlier uses, in particular the curvature and length of the engraved lines, are an indication that these engravings may have been functional re-adjustments. They can therefore be regarded as a kind of repair of the baton after the perforation has become significantly distorted, beveling outward due to significant wear.


a
b
c

The functional use of the Gough's Cave batons could also be inferred by the presence of incisions on the shaft of the batons that may have improved grip on the smooth antler surface. In the case of the Gough's Cave batons, both NHMUK PA E 7783 and NMH PV E 7782 have incisions that recede obliquely from the corner of the perforation, and, in the case of NHMUK PA E 7782, spiral around the shaft. The engraving procedures on the shafts of the Gough's Cave batons are clearly different to those that overlay the concave wear at the edge of the perforation. The accumulation of numerous incisions on the shafts and their irregular profiles, depths and widths, suggest the engraving was not meticulously performed and confer a rough appearance that is similar to other known functional adjustments, such as adherence striations on the base of some projectile points (Lucas 2014). The Magdalenian antler baton MAN 47729 from the Mas d'Azil (Pyrenees, France; Fig. 11b), despite being significantly altered, does show remnants of engravings similar to those observed on NHMUK PA E 7783, in particular two sets of deep, curved, transverse incisions associated with shallower longitudinal or oblique incisions that create 'scratched' areas.

Modification of baton shafts to increase grip has been previously tested by experimental work and associated with being better suited to effectively coil a rope (Rigaud 2001). This is supported by the Magdalenian antler batons MH 1264 from Laugerie-Basse (Dordogne, France; Rigaud 2001) and MAN 47079 from Gourdan Cave (Pyrenees, France; Schwab 2008) (Fig. 7a), in which the mid-shafts of the batons have been sculpted to imitate ligature marks. Other examples show modifications such as gorges, notches, cupules, spiral grooves, and transverse or oblique incisions, which may have led a rope and improve its adherence to the baton surface (Rigaud 2001). Among the most convincing examples, the Magdalenian antler baton MAN PL 55041 from Le Placard Cave shows a wide and deep groove that spirals around the long upper branch to its distal end (Lompre 2003b; Rigaud 2001) (Fig. 10c). Various interpretations of the use of perforated batons have involved ropes, with hollowed areas possibly designed to allow the rope to pass through. A Magdalenian antler baton from Les Combarelles (Dordogne, France; Peyrony 1934), with a large notch on top of a beveled base, has been notably interpreted as a tent peg. The coiling of a rope around the shaft of the 'Bâton aux ours' MAN 83365 from La Vache Cave (Pyrenees, France; Fig. 10d) has been suggested to explain the making of three sets of three peripheral gorges on the shaft (Clottes and Delporte 2003; Nougier and Robert 1975). The large antler baton MAN 3418 from La Madeleine rock-shelter (Dordogne, France; Fig. 11a) can also be interpreted as modified to increase grip (potentially in order to coil a rope) due to sharp percussion marks creating irregular pits along both faces and both sides. Given the irregularity of the modifications, it seems unlikely that in the case of MAN 3418, this was done for decorative reasons, though for batons that have only transverse or oblique incisions (e.g., Fig. 10b and Fig. 11c), it is more difficult to disassociate the engravings performed for decorative purposes from those that may have had a functional role instead (or in addition).

To summarize, the Gough's Cave batons display four main features that can be regarded as functional (or possibly functional): (1) presence of alternate concave wear on the perforations' edges, likely caused by an elongated object passing through the perforation; (2) deep curved lines engraved on the concave wear indicative of possible functional re-adjustments of the worn surfaces surrounding the perforation; (3) double fractures implying substantial forces, which may have required further support of the baton, rather than having been directly held in the hand; and (4) bands of incisions on the shafts, which could fit among the modifications potentially designed for coiling a rope. Altogether, they support the hypothesis that the Gough's Cave batons were used in association with ropes (passing through the perforation and coiling around the shaft) and subjected to significant force (until breaking point). The traces observed here may fit with the hypothesis that they were used as cable blockers for habitat structures (such as tents or suspended meat safes; Rigaud 2001 and 2004), as parts of harnesses (Bahn 1976; Pigorini 1877) or a sledge guide (Chauvet 1910), although these latter hypotheses should be corroborated by evidence of early domestication. Equally, it is possible that the batons were used for a purpose not yet put forward.

While perforated batons in general appear to have been used extensively, the Gough's Cave batons, systematically re-worked, were used exhaustively. This exhaustive use likely relates to the scarcity of the seemingly ideal raw material of reindeer antler in the Cheddar Gorge area. The three antler batons are indeed the only reindeer remains in the cave that are clearly attributable to the Magdalenian period (Currant 1986). During this period, "a relative climatic amelioration on regional vegetation during the Lateglacial Interstadial" could explain the potential absence of reindeer in the Cheddar Gorge area, during which time red deer may have occupied their niche (ibid.). Hence, the reindeer antlers that were used to produce the Gough's Cave batons were probably not local, but imported and curated by the people inhabiting the Gorge. The Gough's Cave batons' significant similarities to perforated batons from the European Upper Paleolithic may therefore suggest that the choice of raw material, technique of production, and use pervaded diverse cultural groups and was not necessarily related to the specific challenges of living at different European latitudes.

Conclusion

The three batons from Gough's Cave display a unique combination of functional features, all of which have been identified individually from the European Upper Paleolithic. As the only known examples of perforated batons in the UK, the Gough's Cave batons represent rare data points from northern latitudes of a technology that was otherwise widespread across Europe for ~ 30 millennia. Through our analyses, we have confirmed the irrelevance of previous hypotheses that the Gough's Cave batons, and other perforated batons with similar use-wear, were used for purely symbolic purposes. The sequences of traces visible on the batons show a complex *chaîne opératoire*, in which the raw material was shaped into the primary object, used, and then subsequently re-modified and re-used. It seems likely that this remodification, in which worn areas around the perforations (caused by use) were engraved, was performed in order to remodel the surface of the perforation's edges, after having become distorted through considerable use.

Based on our analyses of the extensive use-wear and fractures across the batons, it is clear that the three batons from Gough's Cave were intensively used until breaking point. The batons are made of reindeer antler, a material biomechanically ideal for resisting considerable forces without breaking, due to its high ductility. Apart from the batons themselves, there are no reindeer remains within the faunal assemblages in Gough's Cave attributed to the Magdalenian period. This has led us to hypothesize that the scarcity of suitable raw materials in the area, which would have allowed them to produce additional perforated batons, encouraged the Magdalenian inhabitants of Gough's Cave to make full use of the existing batons. This may explain why the Gough's Cave batons were used more heavily than at sites where reindeer appear to have been more abundant. Given the combination of large alternate concave wear around the perforations, engravings of curved lines on the perforation edges, consistent fractures at both ends, and engravings of bands of incisions on the shaft, it is likely that the Gough's Cave batons were used in combination with ropes or straps and were subjected to high forces. In particular, they may have been used as cable blockers for habitat structures, as part of animal harnesses, or sledge guides. The latter two hypotheses had been previously disregarded as there has been a lack of evidence of early domestication of relevant fauna, though the question is still discussed. It is equally possible that the Gough's Cave batons were used for a purpose that has yet to be put forward. Experimental studies focusing on the use of batons with ropes and technological analyses of other perforated batons from the Upper Paleolithic may assist us in further narrowing their proximate role.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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