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A 51,000-year-old engraved bone reveals Neanderthals' capacity for symbolic behaviour

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While there is substantial evidence for art and symbolic behaviour in early *Homo sapiens* across Africa and Eurasia, similar evidence connected to Neanderthals is sparse and often contested in scientific debates. Each new discovery is thus crucial for our understanding of Neanderthals' cognitive capacity. Here we report on the discovery of an at least 51,000-year-old engraved giant deer phalanx found at the former cave entrance of Einhornhöhle, northern Germany. The find comes from an apparent Middle Palaeolithic context that is linked to Neanderthals. The engraved bone demonstrates that conceptual imagination, as a prerequisite to compose individual lines into a coherent design, was present in Neanderthals. Therefore, Neanderthal's awareness of symbolic meaning is very likely. Our findings show that Neanderthals were capable of creating symbolic expressions before *H. sapiens* arrived in Central Europe.

The European Upper Palaeolithic is well known for its outstanding art and symbolic objects. The early phase of these cultural expressions is connected to the Aurignacian dating to c. 43–34 calibrated thousand years before present (ka cal BP[1–5]). Early examples of Upper Palaeolithic cave art are reported from northern Spain and southern France, including those from Grotte Chauvet[6,7]. The Chauvet paintings most probably represent two phases dating to 37–33.5 and 31–28 ka cal BP[8]. In Central Europe, the earliest musical instruments as well as anthropomorphic and zoomorphic ivory figurines are associated with Aurignacian layers in four caves in the Swabian Jura[9,10]. Most famous is the so-called lion man from the Hohlenstein-Stadel cave[11]. Female figurines from Aurignacian layers at Hohle Fels and Stratzing in Lower Austria constitute the earliest human figurines in Europe[12,13]. Recently, the Bachokirian in Southeastern Europe has been assigned to *Homo sapiens*, and cave bear tooth pendants dating to 45.5 ka cal BP were reported too[14]. Today, there is no doubt that a broad spectrum of symbolic behaviour including elaborate mobile and sophisticated cave art is connected to early *H. sapiens* in various parts of Europe.

By contrast, extensive debates surround the question of early hominins' and Neanderthals' cognitive capacities, particularly regarding the ability to create art and symbolic expressions. There is now considerable evidence for elaborate lithic technology[15,16], manufacture of effective wooden weapons and bone tools[17–25]. Also, the production of birch tar adhesives and composite tools is attested for Neanderthals[26,27].

Evidence of personal adornment and symbolic behaviour in Neanderthals, however, is sparse and, if present, it is often debated whether it was in fact adopted through interactions with early *H. sapiens*[14,28–30]. Personal adornment in the form of bone and tooth pendants from the Châtelperronian sites Arcy-sur-Cure and Quinçay in Western Europe has been discussed in that context[31,32]. Furthermore, the wearing of bird feathers, talons and phalanges as jewellery has been suggested at various sites in Southern and Western Europe[33–36].

Middle Palaeolithic cave art was also recently reported from the Iberian caves La Pasiega, Maltravieso and Ardales, based on uranium–thorium dating of calcretes that cover simple wall paintings and a hand stencil[37]. The early age of this cave art, however, is currently subject to debate[38–40]. A few bone and rock items engraved with geometric line patterns have been reported in Neanderthal contexts, but some remain ambiguous[30,41–47].

While there is little doubt that 'symbolic behaviour' in Neanderthals has been underestimated in the past, for the moment it remains an open question to what extent complex expressions of symbolic behaviour and art were present in Central Europe before the arrival of early *H. sapiens*. Our findings contribute important new information to this discussion. Located at ~51° N, Einhornhöhle in Lower Saxony, Germany, is situated along the northern boundary of the world known to be inhabited by Neanderthals. Here, we present an engraved bone that was discovered during recent excavations at the former cave entrance (layer 4.5; Fig. 1).

Results

The engraved bone from Einhornhöhle. *Site and find context.* Einhornhöhle was formed by chemical dissolution of dolomitic rock during the Tertiary period in the Harz Mountains[48]. It is a well-known Quaternary fossil site that has been frequented by treasure hunters since the Middle Ages, aiming to extract what they believed to be unicorn fossils. The first Middle Palaeolithic artefacts were found in 1985 in the Jacob-Friesen Gallery[49–51] (Supplementary Information, and Supplementary Figs. 1 and 2).

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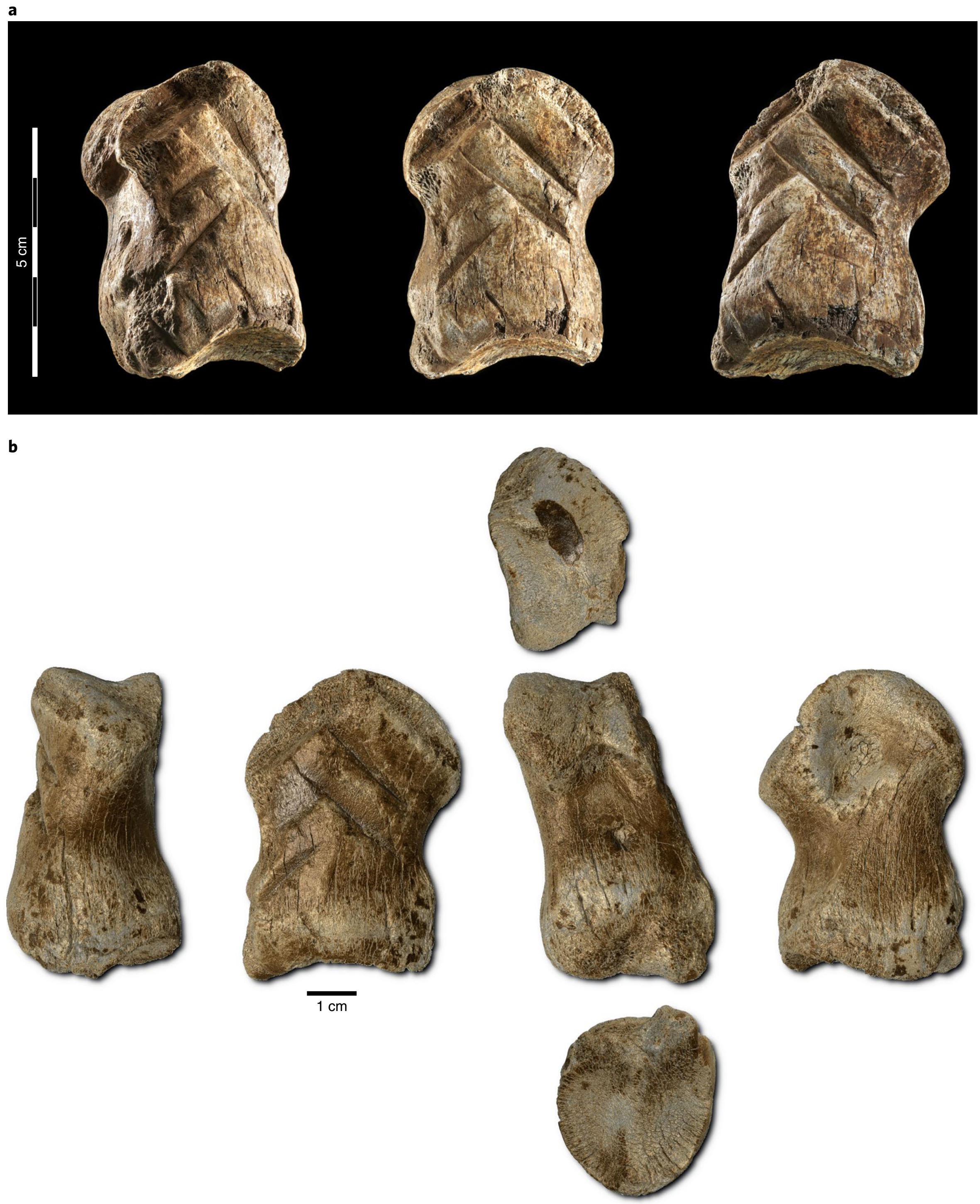

Fig. 1 | Engraved giant deer phalanx (inventory number 46999448-423) from a late Middle Palaeolithic context (layer 4.5) at Einhornhöhle, Lower Saxony, Germany. a, Engraved side in different perspectives. **b**, Six standard views of the same bone generated from micro-CT scans. A 3D video is available at https://denkmalpflege.niedersachsen.de/live/institution/mediadb/mand_45/psfile/bild/57/CC_BY_SA_3606c7d7aad00b.mp4. Credit: V. Minkus.

Since 2014, we have been conducting excavations inside the Jacob-Friesen Gallery, which have yielded six superimposed Middle Palaeolithic layers (D–I) beneath three archaeologically sterile ones (A–C)[51]. Radiometric dates suggest a Holocene age for layer A, an age of >47 ka cal BP for the A/B boundary, >47 ka cal BP for layer B, 54–65 ka BP (electron spin resonance) for layer D and 80–130 ka BP (electron spin resonance) for the earlier layers (E–I).

Excavations also have been undertaken at the prehistoric cave entrance, which is today sealed off by sediments and roof fall (area 4; Supplementary Information and Supplementary Figs. 1–4). A first test trench was dug in 1988 (1 × 2 × 3.5 m), but it was not until 2017 that archaeological layers were discovered[51]. The cave roof is partially eroded, while the entrance is c. 3 m wide at the narrowest point. Collapsed roof material (rocks ≤50 cm) was present up to 2 m

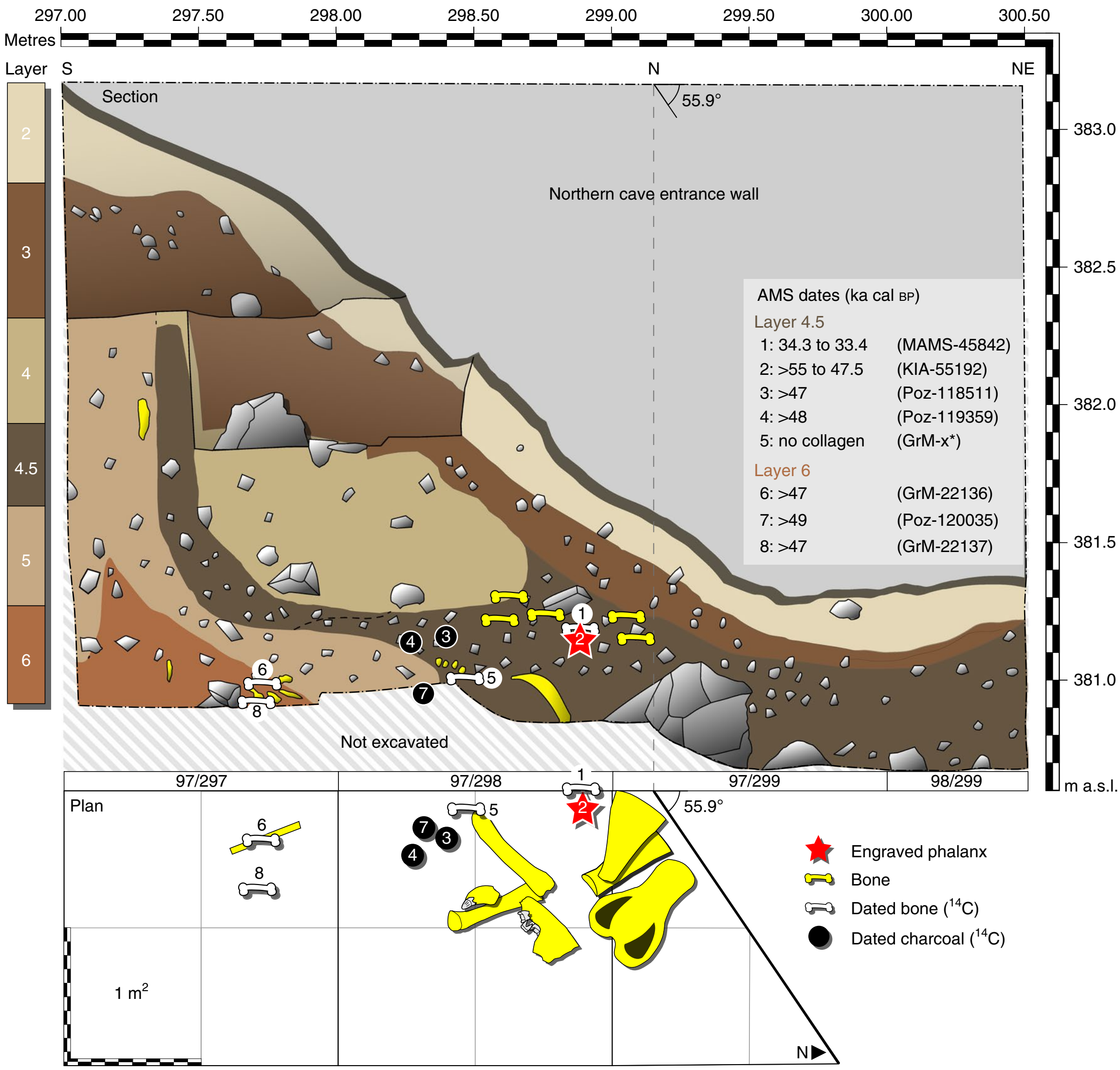

Fig. 2 | Plan and section drawing of the former cave entrance area at Einhornhöhle, including the chronostratigraphic assignment of individual radiometric samples. The incised bone was found among the cave bear bone agglomeration in the north west (squares 97/298 and 97/299).

east of the exposed cave entrance. Sediments are preserved between the northern and the southern entrance walls, as well as along the adjacent slopes. The sediments consist of clayey silt with minor sand components, while weathering indices are high (Supplementary Information and Supplementary Fig. 5). They contain eroded roof material such as rocks and silt (layers 1, 4 and 7), material filled in through a roof cavity (layer 6), and material that sloped down from above the cave roof, followed by in situ weathering (layers 2, 3, 4.1 and 4.5). Layer 4.5 at the former cave entrance probably correlates with layer B inside the Jacob-Friesen Gallery, as both layers show similar sedimentary characteristics, such as grain size distribution, pH-value and mineral content (Supplementary Information and Supplementary Fig. 5).

Excavations at the cave entrance have yielded three non-diagnostic lithic finds (Supplementary Fig. 2), a cortical flake (top of layer 3), a bladelet fragment with one central ridge (layer 4.5) and a further bladelet fragment with two parallel ridges (layer 7). The lithics are made of siliceous slate that is available from local river gravels[50].

Bison (*Bison* sp.), red deer (*Cervus elaphus*), giant deer (*Megaloceros giganteus* (Blumenbach 1799)) and cave lions (*Panthera spelaea*) have been identified in layer 6, while most of the faunal remains from layer 4.5 are taxonomically assigned to bears (*Ursus spelaeus*; $n=29$) and unidentified medium-sized mammals ($n=29$; Supplementary Information and Supplementary Table 1). Furthermore, giant deer (*M. giganteus*; $n=12$ including 10 teeth) and bos/bison (*Bos/bison* sp.; $n=10$) have been identified in layer 4.5 (Supplementary Fig. 6). Despite the small size of the excavated volume in layer 4.5 (1.1 m^3), faunal remains are abundant (number of individual specimens $=99$). Anthropogenic modifications on layer 4.5 materials are present on bos/bison, giant deer (incised phalanx) and possibly red deer and cave bear bones ($n=17$; Supplementary Fig. 7). Carnivore modifications are frequent ($n=53$); however, the degree of damage per specimen is minimal, and the majority of causative agents were small in size. Most of the faunal remains from layer 4.5 are well preserved with limited weathering, low fragmentation, and only a few examples of root etching (Supplementary Table 2) resulting from rapid sedimentation soon after humans and animals had access to faunal remains.

Among the findings is the engraved giant deer second phalanx (inventory number 46999448-423; Fig. 1). The item was located near the west section of layer 4.5 that consists of brown to grey-brown clayey silt and contains pockets of small, edge-rounded dolomitic stones (1–2 cm diameter) and rocks (<10 cm diameter; Fig. 2 and Supplementary Fig. 4). The bone was found in a near-horizontal

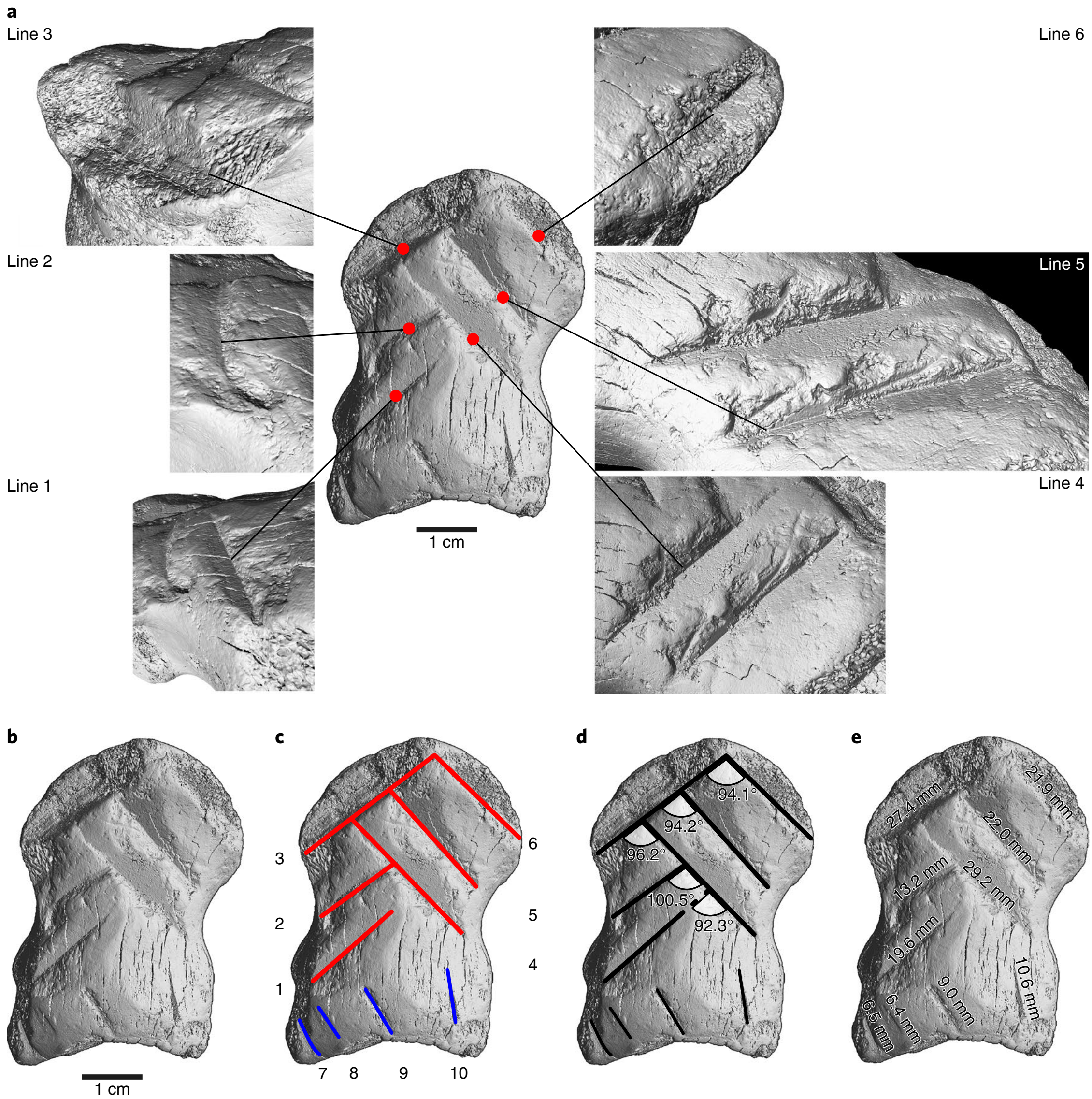

Fig. 3 | Technological details of the incised bone from Einhornhöhle. Greyscale images were generated via micro-CT scanning. **a**, Close-up view of individual engravings. **b**, Blank view of the engraved side. **c**, Line interpretation and line numbers. **d**, Surface angles between individual lines. **e**, Line lengths.

position with a NNW–SSE orientation in one of the stone-rich pockets that grades into an underlying homogeneous sediment pocket (Supplementary Figs. 4 and 8).

The stone-rich pocket associated with the incised bone shows little evidence for sediment sloping, while the homogeneous sediment contains bones that show increased inclinations and multiple orientations. No indication of slope movement or water flow leading to mono-orientation[52] is observed, instead, the data suggest relatively little disturbance connected to the surroundings of the incised bone, whereas other parts of layer 4.5 and especially layer 6 show clearer signs of movement.

The engraved bone was discovered among an accumulation of cave bear bones, including a skull and two cervid shoulder blades piled on top of each other (Supplementary Fig. 9). The engravings of the bone item were identified during the cleaning process.

The incised giant deer phalanx. The second phalanx of a giant deer (*M. giganteus*; length: 56.8 mm; width: 39.9 mm; thickness: 30.9 mm; mass: 36.1 g) with a comparable preservation to the other bones of the layer shows ten carvings on its sinistral side (Fig. 3).

The dominant line pattern consists of a set of six engravings that form five stacked offset chevrons. Sets of lines on either side run more or less parallel and intersect one another in an offset manner. Individual engravings meet at angles of between 92.3 and 100.5°, only engraving 1 has no physical connection to any other engraving (Supplementary Table 3).

Line 4 truncates lines 2 and 3. Lines 3 and 6 are in parts preserved, which prohibits identification of a succession with either line 5 or with each other (Supplementary Information and Supplementary Fig. 10). Lines 2 and 3 are thus older than line 4.

Line lengths range from 13.2 (engraving 2) to 29.2 mm (engraving 4). A detailed investigation of engravings 1, 2, 4 and 5 shows that horizontal surfaces (that is, those parallel to the bone surface) are plain and continuous, whereas vertical surfaces of the same feature are often stepped and oblique (Figs. 3 and 4). This suggests that different carving techniques were used to create the two surfaces. Horizontal surfaces can be up to 6.3 mm wide (engraving 5), while vertical surfaces are between 0.5 and 2.7 mm deep (Supplementary Figs. 11 and 12).

Inner profile angles were measured at the centre point of each engraving, showing a range from 127.0 to 149.4° on the left-hand side (engravings 1–3) and from 66.8 to 102.3° on the right (engravings 4–6; Supplementary Table 2).

A second line pattern consisting of four short lines is located at the proximal end of the bone. Engravings 7–9 run more or less parallel with horizontal inclination angles of between 114 and 123°. Engraving 10 is set apart to the right side with an inclination angle of 98.7°. The lengths of these engravings range from 6.4 (engraving 8) to 10.6 mm (engraving 10).

The observed incisions substantially differ in location, depth and profile from well-known unintentional modifications (for example, butchering, percussion and trampling marks)[53–57]. Cut marks inflicted with lithics commonly create incision depths well below <100 μm, while the incisions on the modified bone are 10 to 50 times deeper. Common cut marks have V- to U-shaped profiles, whereas incisions 1–6 are L-shaped (Supplementary Fig. 12). Also, unintentional modifications lack the horizontal plane adjacent to the vertical cut that is a typical feature of lines 1–6 (Figs. 3 and 4).

Furthermore, the item is of no practical use. Its small size, convex surfaces and instability when lain on the ground prohibit efficient usage as a chopping board or a processing surface. Instead, the geometric pattern itself constitutes the central element. The six lines form two interlaced line sets (left side: lines 1–3; right side: lines 4–6) that each are composed of three parallel incisions. The parallel and regularly spaced engravings have comparable dimensions and were very probably created in a uniform approach suggesting an intentional act. Only the composition of individual lines results in a complex design. The use of a giant deer phalanx—a very impressive herbivore—as raw material emphasizes the special character of the modified item, particularly given the paucity of giant deer at 55–35 ka cal BP north of the Alps[58], which further supports the notion of symbolic meaning.

Potential use-wear such as surface polish or chipping of projected areas (Fig. 3 and Supplementary Fig. 10), which might indicate wearing, for example, as a pendant[59], remains inconclusive as similar traces could have been inflicted by post-depositional processes, or during the engraving procedure. The base of the phalanx, on the other hand, is suitable as a platform on which the item stands upright, with the chevrons pointing upwards. This orientation is also suggested by the incisions at the base of the phalanx. A designation as a premeditated object that had symbolic meaning is thus the most plausible interpretation for the incised bone.

Experimental studies. To better understand the manufacturing process of the engraved item, a set of experiments was carried out and results have been compared with features observed on individual engravings (Supplementary Information, and Supplementary Figs. 13 and 14). By doing so, we aimed to address (1) which techniques were used to create the grooves; and (2) what the best conditions were to carve these grooves (carving time, groove depth, workability and success). Purpose-made blades of Baltic flint were used to manually carve five phalanges (phalanx media) of an 18-month-old Limousin cow by cutting (vertical planes) and scraping (horizontal planes). Each phalanx was treated differently: bone 1 was as fresh, bone 2 was room dried, bone 3 was open air dried, bone 4 was boiled once and bone 5 was boiled twice. A test of soaking bone in water to soften the cortical surface thus enabling an easier carving process was unsuccessful (Supplementary Methods).

The phalanges were handheld during the carving experiment, with their proximal end pointed towards the experimenter. The bone surface was first cut vertically at an approximate 90° angle (Fig. 5). Vertical cutting was performed in a back-and-forth motion similar to the use of a saw. This was followed by scraping of the adjacent horizontal surface towards the vertical cut. Whenever the resulting incision was not deep enough (~2 mm), the vertical surface was cut once again followed by a second phase of horizontal scraping. The repetition of the two techniques resulted in engravings of up to 2 mm depth that bear steep, sometimes stepped vertical edges associated with a wider horizontal surface (Supplementary Fig. 14). Two blades were used to make each incision as their edges became dull within just a few minutes, seemingly depending on bone pre-treatment—sooner with dried bones and later with cooked bones.

To create grooves with a depth of 2 mm, once or repeatedly boiled bones (bones 4 and 5) appear to be the material of choice. They offer a mellow surface and provide enough firm grip to easily handle the tool. Less suitable are dried bones (bones 2 and 3) with soft tissue remains, as steady working of the surface is almost impossible and the bone tissue remains notably harder. Fresh bone (bone 1) seems to be unsuitable, as remaining fresh soft tissue makes the surface greasy and slippery thus leading to total loss of tool control. Similar issues were noticed when decaying bone was cut during experiments[60].

In conclusion, the use of boiled bones seems the most likely option to create controlled grooves with depths of c. 2 mm in a relatively short time (c. 10 mins each; Supplementary Tables 5 and 6). The carvings on the giant deer phalanx from Einhornhöhle thus could have been made within c. 1.5 h. A combination of cutting and scraping has proved a successful working method and the experimental traces closely resemble those observed on the engraved item. There was no (macroscopically) visual difference between fresh and boiled bone.

Micro-traces on the incised giant deer phalanx. Lines 1, 4, and 5 show V-shaped striations (Figs. 3–5, and Supplementary Figs. 12, 15 and 16) consistent with cut marks caused by unretouched flint tools[53–56]. The stepped and rounded-stepped vertical surfaces of lines 2–5 are consistent with traces created during the experiment when they had been inflicted by alternating vertical cutting and horizontal scraping repetitions.

The profiles of lines 2–5 plunge steeply, after reaching the base of the cut they ascend sharply forming a micro-concavity, whereupon they descend slowly forming a micro-convexity (Figs. 3–5, and Supplementary Figs. 12, 15 and 16). It can be hypothesized that this pattern results from scraping and was caused by differently applied pressure and/or numbers of repetitions, whereby areas near the vertical surface had been engraved deeper than more distant ones. This can explain the rippled horizontal surface of the deepest incision, line 3, alternatively, different tools/gestures might have been applied. Line 6 is incomplete, but its partially preserved horizontal surface compares well to the surfaces achieved by the experiment.

Rounding and chipping of vertical edge summits, a phenomenon that was also observed during the experiment, might have been caused during the carving procedure.

Radiometric dating. Nine samples from layers 4.5 and 6 were submitted for radiocarbon dating, consisting of three charcoal samples, two non-modified bones, three cut-marked bones and the engraved giant deer phalanx (Supplementary Table 7). The bone samples were dated in three different laboratories, that is, the Leibniz Laboratory for Radiometric Dating and Stable Isotope Research in Kiel (laboratory ID: KIA), the Centre for Isotope Research in Groningen (lab ID: GrM), and the Curt-Engelhorn-Centre of Archaeometry in Mannheim (lab ID: MAMS), while charcoal samples were dated at the Poznan Radiocarbon Laboratory (lab ID: Poz). Seven samples were dated successfully in four different laboratories and provided results of between 33.4 and 50.9 ka cal BP (Fig. 2, Supplementary Table 8 and Supplementary Fig. 17); two samples had no sufficient collagen preserved.

The engraved giant deer phalanx gave a radiocarbon age of 47.8 + 2.8/− 2.1 ka (KIA-55192). A calibration into calendar ages using the enlarged, newly published IntCal20 dataset[61,62] gives a calendar age range from 54.6 to 48.5 ka cal BP with 68.3% probability.

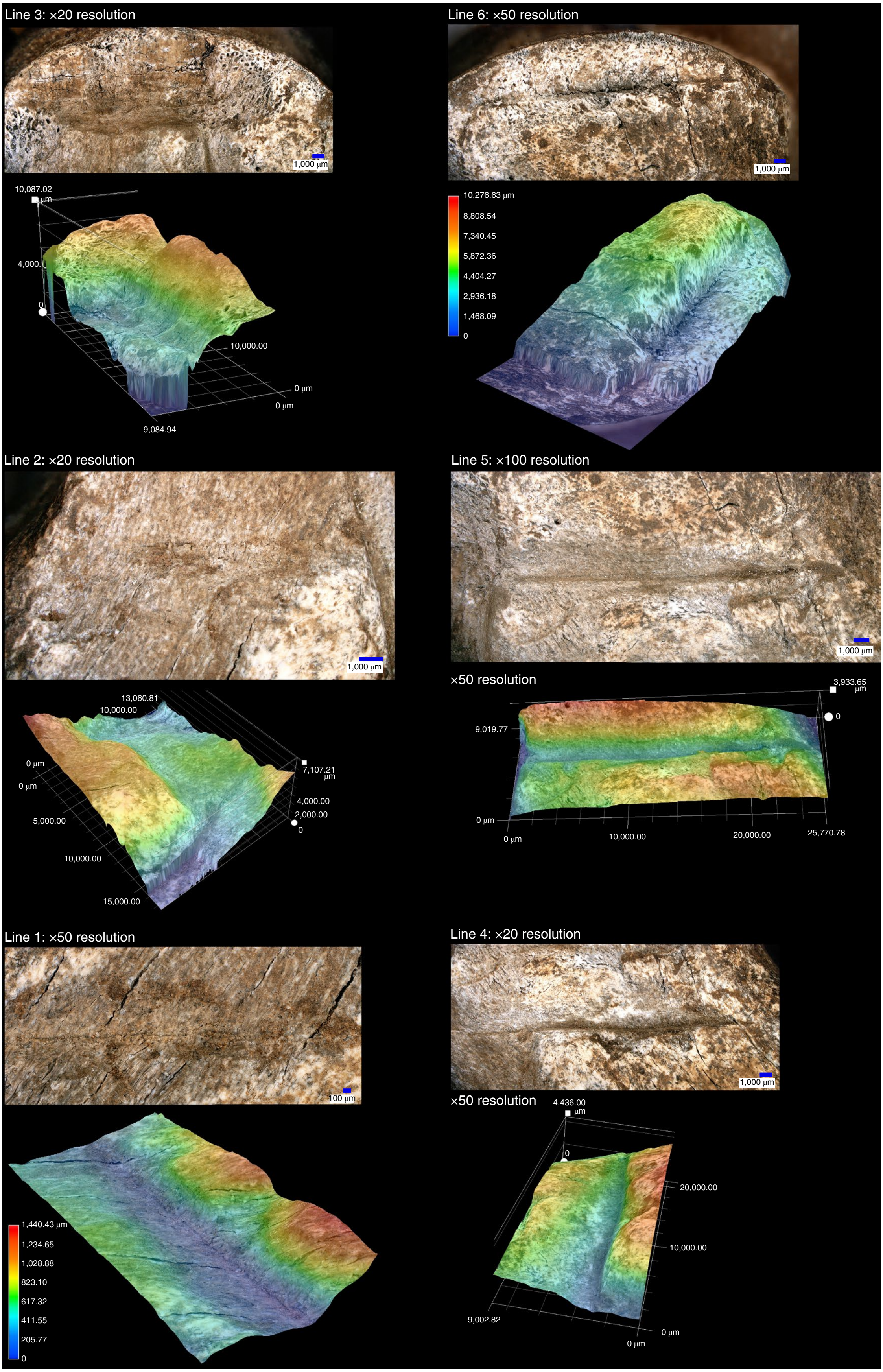

Fig. 4 | 3D digital microscopy images of the carved bone from Einhornhöhle. Stitched images of lines 1–6 with different magnifications and micro-topography images. Greyscale images are provided in Supplementary Fig. 15.

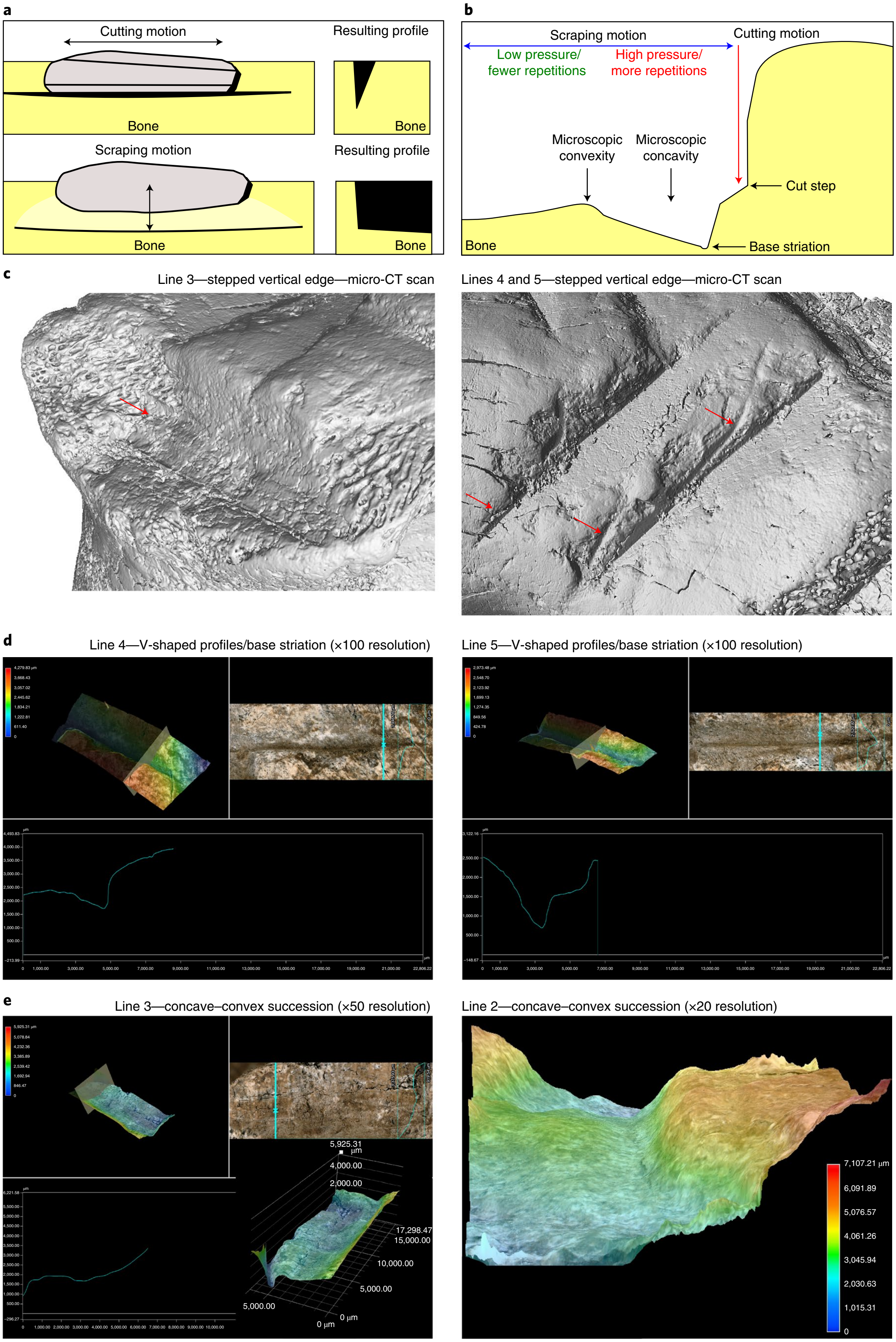

Fig. 5 | Micro-traces of lines 1–6. a, Schematic representation of the cutting and scraping gestures applied during the experiment. **b**, Schematic representation of micro-traces observed on lines 1–6. **c**, Stepped vertical edges of lines 3–5, indicated by the red arrows. **d**, Base striations of lines 4 and 5 displayed as V-shaped profiles. **e**, Succession of concave–convex horizontal surfaces of lines 2 and 3. Greyscale images are provided in Supplementary Fig. 16.

Applying a wider probability range of 95.5%, the minimum calendar age is set at 47.5 ka cal BP, while the older calendar age extends outside the range of the IntCal20 dataset, even implying the possibility of a calibrated age beyond 55 ka cal BP.

Two charcoal dates from the same layer delivered infinite age estimates of >47 ka cal BP (Poz-118511: >45 ka BP) and >48 ka cal BP (Poz-119359: >46 ka BP). They corroborate the date of the incised phalanx from the same layer. A younger date of 34.3 to 33.4 ka cal BP (MAMS-45842: 29.3 ± 180 ka BP) comes from an animal jaw fragment that was found above the incised bone in layer 4.5 close to layer 3 (Fig. 2). The jaw does not bear any signs of human processing.

Two cut-marked bones from the underlying layer 6 also delivered infinite dates of >47 ka cal BP (GrM-22136 and GrM-22137: >45 ka BP). A third date on a pine charcoal from this layer equally delivered an infinite age of >49 ka cal BP (Poz-120035: >47 ka BP).

All radiocarbon dates yielded results near or beyond the radiocarbon boundary. They are in good agreement with their stratigraphic order. Only the jaw bone (MAMS-45842) from above the giant deer phalanx (KIA-55192) yielded a deviating age that might best be explained by the very low collagen content (0.2%; Supplementary Table 6) and/or minor contamination generally resulting in much younger age estimates[63].

In conclusion, the humanly modified phalanx is directly dated and, along with the other radiocarbon dates that are beyond the radiocarbon limit, strongly suggests that the artefact is least 51,000 years old (Supplementary Table 8 and Supplementary Fig. 17).

Discussion

The engraved giant deer phalanx from Einhornhöhle displays a geometric line pattern consisting of two interlaced line sets, each with three parallel lines. A secondary pattern consists of four short lines. The complex production process leading to the creation of the incisions, their systematic arrangement and the scarcity of giant deer north of the Alps, support the notion of an intentional act and of symbolic meaning. Besides the engraved bone from Einhornhöhle, a few bone and rock items with geometric line patterns have been reported from other Middle Palaeolithic contexts that may serve as comparison[30,41–46] (Supplementary Table 9). The materials used as 'canvases' are diverse, including cortical flint, bedrock, tooth and bone. Incisions and engravings on bones have been performed on a range of anatomical body parts coming from animals such as raven, saiga antelope, aurochs and horse. Geometric patterns range from # shapes over zig zags to parallel incisions and circles. In that context, the phalanx from Einhornhöhle with its stacked offset chevrons represents one of the most complex cultural expressions in Neanderthals known so far.

The question remains whether Neanderthals at Einhornhöhle could have been influenced by *H. sapiens* when creating the carved bone. The earliest evidence for the presence of *H. sapiens* in Central Europe comes from several sites in the Upper Danube area, some 400 km to the south[1,3,5,9–13]. They provide early ages of 43.5 to 38 ka cal BP, that is, several millennia after the engraved item from Einhornhöhle was deposited. The earliest *H. sapiens* fossils in remaining Europe come from Southeast Europe, some 1,500 km from Einhornhöhle[14,64,65]. They delivered a maximum age of 45.5 ka cal BP. The geographic and temporal gaps, and the absence of comparable items from early Upper Palaeolithic contexts, make a direct influence improbable. An independent Neanderthal authorship for the engraved bone is thus the most plausible scenario.

The cognitive capacity for creative expressions and social behaviour among early *H. sapiens* has been acknowledged for a long time. In contrast, evidence for symbolic behaviour among early hominins[66] and Neanderthals has remained far more elusive and its independence from *H. sapiens* has often been contested. The engraved bone from Einhornhöhle supports the idea of symbolic behaviour among Neanderthals before the arrival of *H. sapiens* in Central Europe. The cultural influence of *H. sapiens* as the single explanatory factor for abstract cultural expressions in Neanderthals can no longer be sustained[67].

Methods

Analyses of the engraved bone. To better understand the character of the engravings of the giant deer phalanx, the find was subjected to macroscopic and microscopic inspections (three domensional (3D) reflected light microscopy), as well as micro-CT scanning.

Micro-CT scanning was performed by Waygate Technologies GmbH with the aid of a phoenix V|tome|xm micro-CT scanner. Scanning time was c. 1.25 h. The acquired micro-CT data were processed in VGSTUDIO MAX 3.3.4. Colour images were produced to visualise the bone's surface from six standard perspectives. Greyscale images were produced for their higher contrast, allowing us to illustrate details of the engraved surfaces and to optimally present technical information. The lengths, profile depths and internal angles of all incisions were manually measured in VGSTUDIO MAX 3.3.4. Profile angles were measured at the mid-point of the total incision length, and again at 30% and at 70% of the total length. Accordingly, incision depth was measured at the mid-point.

The 3D reflected light microscope Keyence VHX-5000 (Keyence, Neu-Isenburg, Germany) was used for non-destructive, high depth-of-field and 3D images at different magnifications. To examine the engravings of the bone, images of the observation fields were captured at magnifications of ×20, ×50 and ×100. At these magnifications, images in 2D and 3D were taken by means of single image capture and image stitching. Up to 36 individual images were combined to create a stitched image. With the use of such 3D images, topographic profiles of the six engravings were produced. The cross-sectional profile-line measurements were conducted by a straight line intersecting the engravings perpendicularly. The measurement position was displayed by a profile graph in the respective images.

Radiometric dating. Nine samples (3 charcoal, 6 bone) were ^{14}C dated by accelerator mass spectrometry (AMS) at four different laboratories (Supplementary Table 7). All laboratories apply rigorous pre-treatment and dating protocols that do, however, differ in detail (Supplementary Methods). The samples were obtained from two layers that hold the majority of cut-marked bones, that is, layers 4.5 and 6 (Fig. 2 and Supplementary Fig. 4). Cut-marked bones and charcoal were preferred for radiocarbon dating. All charcoal samples were cleaned under a binocular microscope before submission and were identified as pine (*Pinus sylvestris*).

The samples from layer 4.5 were selected according to their proximity to the incised bone (Fig. 2 and Supplementary Fig. 4). One charcoal and two bone samples came from stratigraphic positions above the engraved find (Poz-118511, MAMS-45842 and MAMS-4584). A charcoal and a bone sample were obtained from below the item (Poz-119359 and GrM-x). The modified phalanx was also sampled for absolute dating (KIA-55192). In addition, one charcoal and two bone samples from layer 6 were dated (Poz-120035, GrM-22136 and GrM-22137).

All radiocarbon dates were calibrated with the OxCal 4.4.2 software using the IntCal20 atmospheric curve[61,62]. We also calibrated infinite ages for comparative reasons. To provide a minimum age estimate for them, a theoretical standard deviation of 1,000 radiocarbon years was computed in OxCal 4.4.2 (a similar approach is taken by some radiocarbon labs, such as the Centre for Isotope Research in Groningen). For graphic illustrations the calibrated age ranges were consequently cut off at the minimum age boundary, for example, at 47,000 cal BP for a radiocarbon date >45,000 (Supplementary Fig. 17).

Reporting Summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

A 3D video of the engraved giant deer bone is available online. It is free to view at https://denkmalpflege.niedersachsen.de/live/institution/mediadb/mand_45/psfile/bild/57/CC_BY_SA_3606c7d7aad00b.mp4 and can be downloaded in .mp4 file format under the CC-BY-SA 3.0 licence at https://denkmalpflege.niedersachsen.de/download/167053/CC-BY-SA_3.0.mp4. A 3D model of the engraved giant deer bone can be downloaded in .stl data format under the CC-BY-SA 3.0 licence at https://denkmalpflege.niedersachsen.de/download/166881/CC-BY-SA_3.0.stl. Further datasets generated during and/or analysed during the current study are available from the corresponding authors upon reasonable request.
List of figures with available raw data: Fig. 2—3D coordinate data of finds (.xlxs); Fig. 3—micro-CT scan raw model data (.stl); Figs. 4 and 5—3D digital microscopy images (.jpg, .tiff and so on); Supplementary Fig. 5—3D coordinates of individual samples (A); data spreadsheet for the sample contents (for example, clay %, Dolomite cps and so on) (B, C) as .xlsx; Supplementary Fig. 7—3D coordinate data of finds (.xlxs); Supplementary Fig. 10—micro-CT scan raw model data (.stl); Supplementary Fig. 11—micro-CT scan raw model data (.stl; further photographs of experimental bone traces); Supplementary Fig. 12—3D digital microscopy images (.jpg, .tiff and so on).

Code availability

No custom computer code or custom mathematical algorithm is involved in this study. All data were generated using standard and machine in-built software as stated in the Methods sections of the manuscript and the Supplementary Information, as well as the Reporting Summary.

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References

1. Higham, T. et al. Testing models for the beginnings of the Aurignacian and the advent of figurative art and music: the radiocarbon chronology of Geißenklösterle. *J. Hum. Evol.* **62**, 664–676 (2012).
2. Higham, T. et al. The timing and spatiotemporal patterning of Neanderthal disappearance. *Nature* **512**, 306–309 (2014).
3. Jöris, O., Neugebauer-Maresch, C., Weninger, B. & Street, M. in *New Aspects of the Central and Eastern European Upper Palaeolithic: Methods, Chronology, Technology and Subsistence* (eds Neugebauer-Maresch, C. & Owen, L. R.) 101–137 (Mitteilungen der Prähistorischen Kommission 72, Verlag der Österreichischen Akademie der Wissenschaften, Vienna, 2010).
4. Moreau, L. & Terberger, T. in *Palethnologie du Paléolithique Supérieur Ancien: Où en Sommes Nous?* (eds Bodu, P. et al.) 85–96 (INRAP, 2019).
5. Nigst, P. R. et al. Early modern human settlement of Europe north of the Alps occurred 43,500 years ago in a cold steppe-type environment. *Proc. Natl Acad. Sci. USA* **111**, 14394–14399 (2014).
6. Valladas, H. & Clottes, J. Style, Chauvet and radiocarbon. *Antiquity* **77**, 142–145 (2003).
7. Pike, A. W. G. et al. U-series dating of paleolithic art in 11 caves in Spain. *Science* **336**, 1409–1413 (2012).
8. Quilesa, A. et al. A high-precision chronological model for the decorated Upper Paleolithic cave of Chauvet-Pont d'Arc, Ardèche, France. *Proc. Natl Acad. Sci. USA* **113**, 4670–4675 (2016).
9. Conard, N. J., Malina, M. & Münzel, S. C. New flutes document the earliest musical tradition in southwestern Germany. *Nature* **460**, 737–740 (2009).
10. Floss, H. Same as it ever was? The Aurignacian of the Swabian Jura and the origins of Palaeolithic art. *Quat. Int.* **491**, 21–29 (2018).
11. Kind, C.-J., Ebinger-Rist, N., Wolf, S., Beutelspacher, T. & Wehrberger, K. The smile of the lion man: recent excavations in Stadel Cave (Baden-Württemberg, south-western Germany) and the restoration of the famous Upper Palaeolithic figurine. *Quartär* **61**, 129–145 (2014).
12. Conard, N. J. A female figurine from the basal Aurignacian of Hohle Fels Cave in southwestern Germany. *Nature* **459**, 248–252 (2009).
13. Neugebauer-Maresch, C. Zum Neufund einer weiblichen Statuette an der Aurignac-Station Stratzing/Krems-Rehberg, Niederösterreich. *Germania* **67**, 551–559 (1989).
14. Hublin, J. J. et al. Initial Upper Palaeolithic *Homo sapiens* from Bacho Kiro Cave, Bulgaria. *Nature* **581**, 299–302 (2020).
15. Boëda, E. *Le Concept Levallois: Variabilité des Méthodes* Monographie du CRA 9 (CNRS, Paris, 1994).
16. Muller, A., Clarkson, C. & Shipton, C. Measuring behavioural and cognitive complexity in lithic technology throughout human evolution. *J. Anthropol. Archaeol.* **48**, 166–180 (2017).
17. Thieme, H. Lower Palaeolithic hunting spears from Germany. *Nature* **1997**, 807–810 (1997).
18. Schoch, W. Holzanatomische Nachuntersuchungen an der eemzeitlichen Holzlanze von Lehringen, Ldkr. Verden. *Nachr. Nieders Urgesch.* **83**, 19–29 (2014).
19. Gaudzinski, S. Middle Palaeolithic bone tools from the open-air site Salzgitter-Lebenstedt (Germany). *J. Archaeol. Sci.* **26**, 125–141 (1999).
20. Julien, A.-M. et al. Characterizing the Lower Paleolithic bone industry from Schöningen 12 II: a multi-proxy study. *J. Hum. Evol.* **89**, 264–286 (2015).
21. Schoch, W. H., Bigga, G., Böhner, U., Richter, P. & Terberger, T. New insights on the wooden weapons from the Paleolithic site of Schöningen. *J. Hum. Evol.* **89**, 214–225 (2015).
22. Staesche, U. in Die Tierknochenfunde der mittelpaläolithischen Jägerstation von Salzgitter-Lebenstedt (eds Ludowici, B. & Pöppelmann, H.) 71–86 (Forschungen und Berichte des Braunschweigischen Landesmuseums 1, Verlag Uwe Krebs, 2018).
23. van Kolfschoten, T., Parfitt, S. A., Serangeli, J. & Bello, S. M. Lower Paleolithic bone tools from the 'Spear Horizon' at Schöningen (Germany). *J. Hum. Evol.* **89**, 226–263 (2015).
24. Soressi, M. et al. Neandertals made the first specialized bone tools in Europe. *Proc. Natl Acad. Sci. USA* **110**, 14186–14190 (2013).
25. Aranguren, B. et al. Early Neanderthal wooden artifacts from Italy. *Proc. Natl Acad. Sci. USA* **115**, 2054–2059 (2018).
26. Mania, D. & Töpfer, V. *Königsaue: Gliederung, Ökologie und Mittelpaläolithische Funde der letzten Eiszeit.* Veröffentlichungen des Landesmuseums für Vorgeschichte in Halle 26 (VEB Deutscher Verlag der Wissenschaften, 1973).
27. Niekus, M. J. L. T. et al. Middle Paleolithic complex technology and a Neandertal tar-backed tool from the Dutch North Sea. *Proc. Natl Acad. Sci. USA* **116**, 22081–22087 (2019).
28. Bar-Yosef, O. & Bordes, J. G. Who were the makers of the Châtelperronian culture? *J. Hum. Evol.* **59**, 586–593 (2010).
29. d'Errico, F. D., Zilhão, J., Julien, M., Baffier, D. & Pelegrin, J. Neanderthal acculturation in Western Europe? A critical review of the evidence and it's interpretation. *Curr. Anthropol.* **39**, S1–S44 (1998).
30. Zilhão, J. in *Origins of Human Innovation and Creativity* (ed. Elias, S.) 35–49 (Developments in Quaternary Science 16, Elsevier, 2012).
31. Hublin, J. J. et al. Radiocarbon dates from the Grotte du Renne and Saint-Césaire support a Neandertal origin for the Châtelperronian. *Proc. Natl Acad. Sci. USA* **109**, 18743–18748 (2012).
32. Welker, F. et al. Palaeoproteomic evidence identifies archaic hominins associated with the Châtelperronian at the Grotte du Renne. *Proc. Natl Acad. Sci. USA* **113**, 11162–11167 (2016).
33. Peresani, M., Fiore, I., Gala, M., Romandini, M. & Tagliacozzo, A. Late Neandertals and the intentional removal of feathers as evidenced from bird bone taphonomy at Fumane Cave 44 ky B.P., Italy. *Proc. Natl Acad. Sci. USA* **108**, 3888–3893 (2011).
34. Radovčić, D., Sršen, A. O., Radovčić, J. & Frayer, D. W. Evidence for Neandertal jewellery: modified white-tailed eagle claws at Krapina. *PLoS ONE* **10**, e0119802 (2015).
35. Romandini, M. et al. Convergent evidence of eagle talons used by late Neanderthals in Europe: a further assessment on symbolism. *PLoS ONE* **9**, e101278 (2014).
36. Rodríguez-Hidalgo, A. et al. The Châtelperronian Neanderthals of Cova Foradada (Calafell, Spain) used imperial eagle phalanges for symbolic purposes. *Sci. Adv.* **5**, eaax1984 (2019).
37. Hoffmann, D. L. et al. U–Th dating of carbonate crusts reveals Neandertal origin of Iberian cave art. *Science* **359**, 912–915 (2018).
38. Slimak, L., Fietzke, J., Geneste, J. M. & Ontañón, R. Comment on "U-Th dating of carbonate crusts reveals Neandertal origin of Iberian cave art". *Science* **361**, eaau1371 (2018).
39. White, R. et al. Still no archaeological evidence that Neanderthals created Iberian cave art. *J. Hum. Evol.* **144**, 012640 (2020).
40. Hoffmann, D. L. et al. Response to White et al.'s reply: 'Still no archaeological evidence that Neanderthals created Iberian cave art' [J. Hum. Evol. (2020) 102640]. *J. Hum. Evol.* **144**, 102810 (2020).
41. Majkić, A., Evans, S., Stepanchuk, V., Tsvelykh, A. & d'Errico, F. A decorated raven bone from the Zaskalnaya VI (Kolosovskaya) Neanderthal site, Crimea. *PLoS ONE* **12**, e0173435 (2017).
42. Majkić, A., d'Errico, F. & Stepanchuk, V. Assessing the significance of Palaeolithic engraved cortexes. A case study from the Mousterian site of Kiik-Koba, Crimea. *PLoS ONE* **13**, e0195049 (2018).
43. Rodríguez-Vidal, J. et al. A rock engraving made by Neanderthals in Gibraltar. *Proc. Natl Acad. Sci. USA* **111**, 13301–13306 (2014).
44. Shaham, D., Belfer-Cohen, A., Rabinovich, R. & Goren-Inbar, N. A Mousterian engraved bone: principles of perception in Middle Paleolithic art. *Curr. Anthropol.* **60**, 708–716 (2019).
45. Stepanchuk, V. Prolom II, a Middle Palaeolithic cave site in the eastern Crimea with non-utilitarian bone artefacts. *Proc. Prehist. Soc.* **59**, 17–37 (1993).
46. Prévost, M., Groman-Yaroslavski, I., Crater Gershtein, K. M., Tejero, J.-M. & Zaidner, Y. Early evidence for symbolic behavior in the Levantine Middle Paleolithic: a 120 ka old engraved aurochs bone shaft from the open-air site of Nesher Ramla, Israel. *Quat. Int.* https://doi.org/10.1016/j.quaint.2021.01.002 (2021).
47. Peresani, M. et al. Symbolic or utilitarian? Juggling interpretations of Neanderthal behavior: new inferences from the study of engraved stone surfaces. *J. Anthropol. Sci.* **92**, 233–255 (2014).
48. Röhling, H. G. et al. An integrated geophysical and geological interpretation of the area around Unicorn Cave (Southern Harz Mountains, Germany). *Z. Dtsch. Ges. Geowiss.* **170**, 117–144 (2019).
49. Nielbock, R. Die Tierknochenfunde der Ausgrabungen 1987/88 in der Einhornhöhle bei Scharzfeld. *Archäologisches Korrespondenzblatt* **19**, 217–230 (1989).
50. Veil, S. Die archäologisch-geowissenschaftlichen Ausgrabungen 1987/1988 in der Einhornhöhle bei Scharzfeld, Ldkr. Osterode am Harz. *Archäologisches Korrespondenzblatt* **19**, 203–215 (1989).
51. Kotula, A. et al. Eiszeitliche Besiedlung in Niedersachsens Höhlen: Neue Forschungen an der Einhornhöhle im Harz, Ldkr. *Göttingen. Nachr. Nieders Urgesch.* **88**, 211–229 (2019).
52. Dibble, H. L., Chase, P. G., McPherron, S. P. & Tuffrerau, A. Testing the reality of a 'living floor' with archaeological data. *Am. Antiquity* **62**, 629–651 (1997).
53. Boschin, F. & Crezzini, J. Morphometrical analysis on cut marks using a 3D digital microscope. *Int. J. Osteoarchaeol.* **22**, 549–562 (2011).
54. Courtenay, L. A., Huguet, R., González-Aguilera, D. & Yravedra, J. A hybrid geometric morphometric deep learning approach for cut and trampling mark classification. *Appl. Sci.* **10**, 150 (2020).

55. Domínguez-Rodrigo, M., Rayne Pickering, T. & Bunn, H. T. Experimental study of cut marks made with rocks unmodified by human flaking and its bearing on claims of ~3.4-million-year-old butchery evidence from Dikika, Ethiopia. *J. Archaeol. Sci.* **39**, 205–214 (2012).
56. Galán, A. B. & Domínguez-Rodrigo, M. An experimental study of the anatomical distribution of cut marks created by filleting and disarticulation of long bone ends. *Archaeometry* **55**, 1132–1149 (2013).
57. Domínguez-Rodrigo, M. & Barba, R. New estimates of tooth mark and percussion mark frequencies at the FLK Zinj site: the carnivore-hominid-carnivore hypothesis falsified. *J. Hum. Evol.* **50**, 170–194 (2006).
58. Lister, A. M. & Stuart, A. J. The extinction of the giant deer *Megaloceros giganteus* (Blumenbach): new radiocarbon evidence. *Quat. Int.* **500**, 185–2013 (2019).
59. Falci, C. G., Cuisin, J., Delpuech, A., Van Gijn, A. & Hofman, C. L. New Insights into use-wear development in bodily ornaments through the study of ethnographic collections. *J. Archaeol. Method Theory* **26**, 755–805 (2019).
60. Wallduck, R. & Bello, S. M. Cut mark micro-morphometrics associated with the stage of carcass decay: a pilot study using three-dimensional microscopy. *J. Archael. Sci. Rep.* **18**, 174–185 (2018).
61. Bronk Ramsey, C. et al. Reanalysis of the atmospheric radiocarbon calibraton record from Lake Suigetsu, Japan. *Radiocarbon* **62**, 989–999 (2020).
62. Reimer, P. et al. The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP). *Radiocarbon* **62**, 735–757 (2020).
63. Hublin, J. J. The last Neanderthal. *Proc. Natl Acad. Sci. USA* **114**, 10520–10522 (2017).
64. Fewlass, H. et al. A ^{14}C chronology for the Middle to Upper Palaeolithic transition at Bacho Kiro Cave, Bulgaria. *Nat. Ecol. Evol.* **4**, 794–801 (2020).
65. Bard, E. et al. Extended dilation of the radiocarbon time scale between 40,000 and 48,000y BP and the overlap between Neanderthals and *Homo sapiens*. *Proc. Natl Acad. Sci. USA* **117**, 21005–21007 (2020).
66. Joordens, J. C. et al. *Homo erectus* at Trinil on Java used shells for tool production and engraving. *Nature* **518**, 228–231 (2015).
67. Zilhão, J. Tar adhesives, Neandertals, and the tyranny of the discontinuous mind. *Proc. Natl Acad. Sci. USA* **116**, 21966–21968 (2019).

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Author contributions

D.L. designed the project, analysed the finds, contributed to the experiments and discussion, and wrote major parts of the text. R.H. designed and performed the bone carving experiment, and contributed to the text. M.H. performed radiocarbon dating and contributed to the text. G.R. analysed faunal remains and contributed to the text. P.H. conducted sediment analysis and contributed to the text. R.N. contributed to project design and field work. U.B. contributed to project design and discussion. J.L. contributed to field work and discussion. M.M. analysed the engraved bone (stereo-microscopy), was responsible for its conservation and contributed to the discussion. A.S. contributed to project design and discussion. A.T.-R. analysed the engraved bone (micro-CT scan) and contributed to the discussion. T.K. analysed the engraved bone (3D digital microscopy) and contributed to the text. T.T. designed the project, contributed to discussion and wrote major parts of the text. D.L.'s position at the State Service for Cultural Heritage Lower Saxony is funded by the Niedersächsisches Ministerium für Wissenschaft und Kultur, who made this research possible through the Pro*Niedersachsen grant no. 76202-76-2/17. The grant also comprises financial support, for example, for archaeological field work, radiocarbon dating and organic material studies. All relevant funding awarded to each author is described in the Acknowledgements section; if not indicated, funding was provided by the authors' institutions.

Competing interests

The authors declare no competing interests.

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Software and code

Policy information about availability of computer code

Data collection	Leica TS06-ultra2 V.4.4 - in-field 3D-coordiantes; micro-CT scans by Waygate Technologies GmbH using a phoenix 322 V|tome|xm micro CT scanner; 3D digital microscopy with Keyence VHXKeyence VHX-5000 with VHX-ZS20 zoom lens
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Further datasets generated during and/or analysed during the current study are available from the corresponding authors upon reasonable request.
List of figures with available raw data
Figure 2 – 3D-coordinate data of finds (.xlsx)
Figure 3 – micro CT-scan raw model data (.stl)
Figures 4 & 5– 3D digital microscopy images (.jpg, .tiff, and the like)
Supplementary Figure 5 – 3D-coordinates of individual samples (A); data spreadsheet for the sample contents (e.g. clay %, Dolomite cps, etc.) (B, C) as .xlsx.
Supplementary Figure 7 – 3D-coordinate data of finds (.xlsx)
Supplementary Figure 10 – micro CT-scan raw model data (.stl)
Supplementary Figure 11 – micro CT-scan raw model data (.stl; further photographs of experimental bone traces).
Supplementary Figures 12– 3D digital microscopy images (.jpg, .tiff, and the like)dinate data of finds
Supplementary Figure 10-11 – micro CT-scan raw model data (.stl)
Supplementary Figure 14 – micro CT-scan raw model data (.stl); Further photographs of experimental bone traces.

Field-specific reporting

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Ecological, evolutionary & environmental sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	The study deals with an engraved giant deer toe bone bearing systematic engravings. Radiometric data shows its association with Neanderthals some 51,000 years ago. Micro CT-scans and 3D digital microscopy illustrate the properties of individual engravings. Experimental studies suggest that the bone was carved in a two-step approach and that planning depth was prerequisite. We discuss the meaning of the object in connection with Neanderthals cognitive abilities and its independence form Homo sapiens.
Research sample	The bone item is a single find. However, comparisons are made with further known finds across Eurasia that imply symbolic expressions in Neanderthals.
Sampling strategy	Bone item: The bone item is a single find. Radiocarbon dates: The sampling strategy is described in the main text and the supplement, especially for the engraved bone. Sediment samples: These were taken from the main inplaces profile where no rocks were visible. The aim was to obtain two samples per layer to ensure within-layer consistency
Data collection	On-site data was collected using a total station. Finds and features were recorded in writing, by photographs, drawings and SfM imagery. The microCT-Scans were performed by Waygate Technologies GmbH, a commercial lab. 3D digital microscopy was performed by Tim Koddenberg. Bones and charcoals were selected by Thomas Terberger and Dirk Leder and then submitted to the various labs for radiocarbon sampling and dating. Sediment samples were collected by Dirk Leder during the final week of excavation and processed by Philipp Hoelzmann. The carving experiment was performed by Raphael Hermann and Dirk Leder and empirical data was collected based on observations and discussion.
Timing and spatial scale	The relevant samples were taken from a small area measuring about 1.5 x 1.5 x 1.0 metres. The duration of the excavation was 8 weeks in August/September 2019 and five weeks in 2020. Post-excavation processing commenced thereafter. Samples for radiometric dating were submitted between November 2019 and May 2020. Sediment samples were submitted in November 2019. Delays in processing are due to the Covid-19 pandemic and its effects.
Data exclusions	No data was exluded.
Reproducibility	We conducted an experiment on cattle bones to better understand the procedure involved in creating the engravings observed on the original find. Applying a cut-and groove technique, we were able to create about eight engravings on differently pretreated bones. The protocol for radiocarbon dating is outlined in the methods secition of the manuscript and detailed in the supplement. A comparative study can be found in Hüls et al. 2017
Randomization	not applicable
Blinding	Blinding was not applied when carving the bones as the experimentators aimed to create engravings that appear similar to those observed on the original piece.

Did the study involve field work? ☒ Yes ☐ No

Field work, collection and transport

Field conditions	The excavtion took place in a mid-latitude broad-leafed forest during summer in front of a former cave entrance that was partially eroded. Weather was mostly sunny, but there were some rainy days. The excavation area was complety sheltered by a white plastic foil roof.

Location	UTM 32N - E: 597097.067 N: 5721298.883 Elev: 381.145 m asl
Access & import/export	Niedersächsisches Landesamt für Denkmalpflege and Gesellschaft Unicornu fossile e.V. signed a collaboration contract in 2014. The Untere Denkmalschutzbehörde Landkreis Göttingen (formely Landkreis Osterode) and the Naturschutzbehörde Landkreis Göttingen (formely Landkreis Osterode) approved the excavation. Samples were 3D-recorded and photographed in the field and carefully placed in plastic bags and containers. Plan and section drawings were made and photographs taken. Individual finds and sample bags were collected in transport boxes and exported by car and van.
Disturbance	The trench left behind by the excavation was partially backfilled and fenced in. Excavations continue annually.

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Palaeontology and Archaeology

Specimen provenance	The finds and sample come from a former cave entrance that by 2014 was completely covered by sediments. The finds and samples reported in the article were obtained through excavation in August/September 2019 and 2020. The necessary permits and collaborations are listed under the section, "Field work, collection and transport".
Specimen deposition	The samples have been deposited with the various specialists for analyses: 1. Gesellschaft Unicornu fossile e.V. – microfauna 2. Institute of Archaeological Sciences, Eberhard Karls University Tübingen – macrofauna 3. Institute of Geographical Sciences, Freie Universität Berlin – sediment samples 4. Various radiocarbon labs – charcoal and bone samples (whenever possible, remaining material was returned) 5. All other materials (including the decorated bone) and documentation are with the Niedersächsisches Landesamt für Denkmalpflege
Dating methods	All necessary information are provided in the main text or the supplementary material.

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Ethics oversight	No ethical approval or guidance was neccessary as no human remains were invloved in the study.

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Field-collected samples	*For laboratory work with field-collected samples, describe all relevant parameters such as housing, maintenance, temperature, photoperiod and end-of-experiment protocol OR state that the study did not involve samples collected from the field.*
Ethics oversight	*Identify the organization(s) that approved or provided guidance on the study protocol, OR state that no ethical approval or guidance was required and explain why not.*

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Human research participants

Policy information about studies involving human research participants

Population characteristics	*Describe the covariate-relevant population characteristics of the human research participants (e.g. age, gender, genotypic information, past and current diagnosis and treatment categories). If you filled out the behavioural & social sciences study design questions and have nothing to add here, write "See above."*
Recruitment	*Describe how participants were recruited. Outline any potential self-selection bias or other biases that may be present and how these are likely to impact results.*
Ethics oversight	*Identify the organization(s) that approved the study protocol.*

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Clinical data

Policy information about clinical studies

All manuscripts should comply with the ICMJE guidelines for publication of clinical research and a completed CONSORT checklist must be included with all submissions.

Clinical trial registration	*Provide the trial registration number from ClinicalTrials.gov or an equivalent agency.*
Study protocol	*Note where the full trial protocol can be accessed OR if not available, explain why.*
Data collection	*Describe the settings and locales of data collection, noting the time periods of recruitment and data collection.*
Outcomes	*Describe how you pre-defined primary and secondary outcome measures and how you assessed these measures.*

Dual use research of concern

Policy information about dual use research of concern

Hazards

Could the accidental, deliberate or reckless misuse of agents or technologies generated in the work, or the application of information presented in the manuscript, pose a threat to:

No	Yes	
☒	☐	Public health
☒	☐	National security
☒	☐	Crops and/or livestock
☒	☐	Ecosystems
☒	☐	Any other significant area

Experiments of concern

Does the work involve any of these experiments of concern:

No	Yes	
☒	☐	Demonstrate how to render a vaccine ineffective
☒	☐	Confer resistance to therapeutically useful antibiotics or antiviral agents
☒	☐	Enhance the virulence of a pathogen or render a nonpathogen virulent
☒	☐	Increase transmissibility of a pathogen
☒	☐	Alter the host range of a pathogen
☒	☐	Enable evasion of diagnostic/detection modalities
☒	☐	Enable the weaponization of a biological agent or toxin
☒	☐	Any other potentially harmful combination of experiments and agents

ChIP-seq

Data deposition

☐ Confirm that both raw and final processed data have been deposited in a public database such as GEO.

☐ Confirm that you have deposited or provided access to graph files (e.g. BED files) for the called peaks.

Data access links *May remain private before publication.*	*For "Initial submission" or "Revised version" documents, provide reviewer access links. For your "Final submission" document, provide a link to the deposited data.*
Files in database submission	*Provide a list of all files available in the database submission.*
Genome browser session (e.g. UCSC)	*Provide a link to an anonymized genome browser session for "Initial submission" and "Revised version" documents only, to enable peer review. Write "no longer applicable" for "Final submission" documents.*

Methodology

Replicates	*Describe the experimental replicates, specifying number, type and replicate agreement.*
Sequencing depth	*Describe the sequencing depth for each experiment, providing the total number of reads, uniquely mapped reads, length of reads and whether they were paired- or single-end.*
Antibodies	*Describe the antibodies used for the ChIP-seq experiments; as applicable, provide supplier name, catalog number, clone name, and lot number.*
Peak calling parameters	*Specify the command line program and parameters used for read mapping and peak calling, including the ChIP, control and index files used.*
Data quality	*Describe the methods used to ensure data quality in full detail, including how many peaks are at FDR 5% and above 5-fold enrichment.*
Software	*Describe the software used to collect and analyze the ChIP-seq data. For custom code that has been deposited into a community repository, provide accession details.*

Flow Cytometry

Plots

Confirm that:

☐ The axis labels state the marker and fluorochrome used (e.g. CD4-FITC).

☐ The axis scales are clearly visible. Include numbers along axes only for bottom left plot of group (a 'group' is an analysis of identical markers).

☐ All plots are contour plots with outliers or pseudocolor plots.

☐ A numerical value for number of cells or percentage (with statistics) is provided.

Methodology

Sample preparation	*Describe the sample preparation, detailing the biological source of the cells and any tissue processing steps used.*
Instrument	*Identify the instrument used for data collection, specifying make and model number.*

Software | *Describe the software used to collect and analyze the flow cytometry data. For custom code that has been deposited into a community repository, provide accession details.*
Cell population abundance | *Describe the abundance of the relevant cell populations within post-sort fractions, providing details on the purity of the samples and how it was determined.*
Gating strategy | *Describe the gating strategy used for all relevant experiments, specifying the preliminary FSC/SSC gates of the starting cell population, indicating where boundaries between "positive" and "negative" staining cell populations are defined.*

☐ Tick this box to confirm that a figure exemplifying the gating strategy is provided in the Supplementary Information.

Magnetic resonance imaging

Experimental design

Design type | *Indicate task or resting state; event-related or block design.*
Design specifications | *Specify the number of blocks, trials or experimental units per session and/or subject, and specify the length of each trial or block (if trials are blocked) and interval between trials.*
Behavioral performance measures | *State number and/or type of variables recorded (e.g. correct button press, response time) and what statistics were used to establish that the subjects were performing the task as expected (e.g. mean, range, and/or standard deviation across subjects).*

Acquisition

Imaging type(s) | *Specify: functional, structural, diffusion, perfusion.*
Field strength | *Specify in Tesla*
Sequence & imaging parameters | *Specify the pulse sequence type (gradient echo, spin echo, etc.), imaging type (EPI, spiral, etc.), field of view, matrix size, slice thickness, orientation and TE/TR/flip angle.*
Area of acquisition | *State whether a whole brain scan was used OR define the area of acquisition, describing how the region was determined.*
Diffusion MRI ☐ Used ☐ Not used

Preprocessing

Preprocessing software | *Provide detail on software version and revision number and on specific parameters (model/functions, brain extraction, segmentation, smoothing kernel size, etc.).*
Normalization | *If data were normalized/standardized, describe the approach(es): specify linear or non-linear and define image types used for transformation OR indicate that data were not normalized and explain rationale for lack of normalization.*
Normalization template | *Describe the template used for normalization/transformation, specifying subject space or group standardized space (e.g. original Talairach, MNI305, ICBM152) OR indicate that the data were not normalized.*
Noise and artifact removal | *Describe your procedure(s) for artifact and structured noise removal, specifying motion parameters, tissue signals and physiological signals (heart rate, respiration).*
Volume censoring | *Define your software and/or method and criteria for volume censoring, and state the extent of such censoring.*

Statistical modeling & inference

Model type and settings | *Specify type (mass univariate, multivariate, RSA, predictive, etc.) and describe essential details of the model at the first and second levels (e.g. fixed, random or mixed effects; drift or auto-correlation).*
Effect(s) tested | *Define precise effect in terms of the task or stimulus conditions instead of psychological concepts and indicate whether ANOVA or factorial designs were used.*
Specify type of analysis: ☐ Whole brain ☐ ROI-based ☐ Both
Statistic type for inference (See Eklund et al. 2016) | *Specify voxel-wise or cluster-wise and report all relevant parameters for cluster-wise methods.*
Correction | *Describe the type of correction and how it is obtained for multiple comparisons (e.g. FWE, FDR, permutation or Monte Carlo).*

Models & analysis

n/a	Involved in the study
☐	☐ Functional and/or effective connectivity
☐	☐ Graph analysis
☐	☐ Multivariate modeling or predictive analysis

Functional and/or effective connectivity	*Report the measures of dependence used and the model details (e.g. Pearson correlation, partial correlation, mutual information).*
Graph analysis	*Report the dependent variable and connectivity measure, specifying weighted graph or binarized graph, subject- or group-level, and the global and/or node summaries used (e.g. clustering coefficient, efficiency, etc.).*
Multivariate modeling and predictive analysis	*Specify independent variables, features extraction and dimension reduction, model, training and evaluation metrics.*