shows that modern human morphology emerged in Africa long before the Neanderthals vanished from Eurasia. □

Methods

Order Primates L., 1758
Suborder Anthropoidea Mivart, 1864
Superfamily Hominoidea Gray, 1825
Family Hominidae Gray, 1825
Homo sapiens idaltu subsp. nov.

Etymology. The subspecies name 'idàltu' is taken from the Afar language. It means 'elder'.
Holotype. BOU-VP-16/1 (Fig. 1), an adult cranium with partial dentition. Holotype and referred material are housed at the National Museum of Ethiopia, Addis Ababa. Holotype from Bouri Vertebrate Paleontology Locality 16 (BOU-VP 16); differentially corrected GPS coordinates: 10° 15.5484′ N and 40° 33.3834′ E.
Referred material. BOU-VP-16/2 cranial fragments; BOU-VP-16/3 parietal fragment; BOU-VP-16/4 parietal fragment; BOU-VP-16/5 child's cranium; BOU-VP-16/6 R. upper molar; BOU-VP-16/7 parietal fragment, BOU-VP-16/18 parietal fragments; BOU-VP-16/42 upper premolar, BOU-VP-16/43 parietal fragment.
Stratigraphy and age. Bouri Formation, Upper Herto Member. Dated by $^{40}Ar/^{39}Ar$ to between 160,000 and 154,000 years ago (ref. 6).
Diagnosis. On the limited available evidence, a subspecies of *Homo sapiens* distinguished from Holocene anatomically modern humans (*Homo sapiens sapiens*) by greater craniofacial robusticity, greater anterior–posterior cranial length, and large glenoid-to-occlusal plane distance. *Homo sapiens idaltu* is distinguished from the holotype of *Homo rhodesiensis* (Woodward, 1921) by a larger cranial capacity, a more vertical frontal with smaller face, and more marked midfacial topography (for example, canine fossa). We consider the holotypes of *H. helmei* and *H. njarasensis* too fragmentary for appropriate comparisons.

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Stratigraphic, chronological and behavioural contexts of Pleistocene *Homo sapiens* from Middle Awash, Ethiopia

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Clarifying the geographic, environmental and behavioural contexts in which the emergence of anatomically modern *Homo sapiens* occurred has proved difficult, particularly because Africa lacked adequate geochronological, palaeontological and archaeological evidence. The discovery of anatomically modern *Homo sapiens* fossils at Herto, Ethiopia[1], changes this. Here we report on stratigraphically associated Late Middle Pleistocene artefacts and fossils from fluvial and lake margin sandstones of the Upper Herto Member of the Bouri Formation, Middle Awash, Afar Rift, Ethiopia. The fossils and artefacts are dated between 160,000 and 154,000 years ago by precise age determinations using the $^{40}Ar/^{39}Ar$ method. The archaeological assemblages contain elements of both Acheulean and Middle Stone Age technocom-

plexes. Associated faunal remains indicate repeated, systematic butchery of hippopotamus carcasses. Contemporary adult and juvenile *Homo sapiens* fossil crania manifest bone modifications indicative of deliberate mortuary practices.

Pliocene Hatayae Member sediments at the base of the Bouri Formation in Ethiopia's Afar Depression yielded *Australopithecus garhi* and the earliest evidence of the butchery of large mammals by hominids[2]. The overlying 1-million-year-old Dakanihylo Member deposits yielded early Acheulean assemblages associated with skeletal remains of *Homo erectus*[3]. The overlying Herto Member comprises two units that contain later Acheulean and early Middle Stone Age (MSA) implements[4]. The recovery of hominid remains in the Upper Herto Member in 1997 intensified stratigraphic, geochemical, radioisotopic, archaeological and palaeontological studies of these deposits and their contents.

The base of the Herto Member is unconformable on the underlying Dakanihylo Member sandstone. We recognize a major stratigraphic and temporal division within the 15–20-m-thick Herto Member and so designate the Upper and Lower Herto Members. The Lower Herto Member, which resulted from the uplift of the Bouri fault block that diverted the ancestral Awash River and created Yardi Lake, consists of lignite, pinkish carbonate layers, and silty clays of predominantly lacustrine origin bearing gastropods and bivalves. The Lower Herto lithic assemblage is characterized by late Acheulean tool types; hominid remains are as yet unknown[4]. The age of the Lower Herto is established by an included bentonite tuff (MA97-1, 2) usually located within 1 m below the Upper/Lower Herto contact. Although contaminated by xenocrysts, it yields an ^{40}Ar/^{39}Ar age of 260 ± 16 thousand years (kyr; mean ± s.d., here and throughout) defined by the weighted mean age of 24 (of 93) individual alkali feldspar crystals (see Supplementary Information). These Lower Herto sediments grade to fluvial and lake-margin deposits of coarse beach and yellow sandstone of the overlying Upper Herto Member, itself capped by a vitric tuff (WAVT, Waidedo Vitric Tuff, MA92-1; Fig. 1). Abundant archaeological and faunal remains are embedded in a sand unit at the base of the Upper Herto Member, the former characterized by finely made bifaces on flakes, sometimes Levallois flakes.

The contact between Lower and Upper Herto Members is defined here as a widespread erosional surface identified by a fossiliferous,

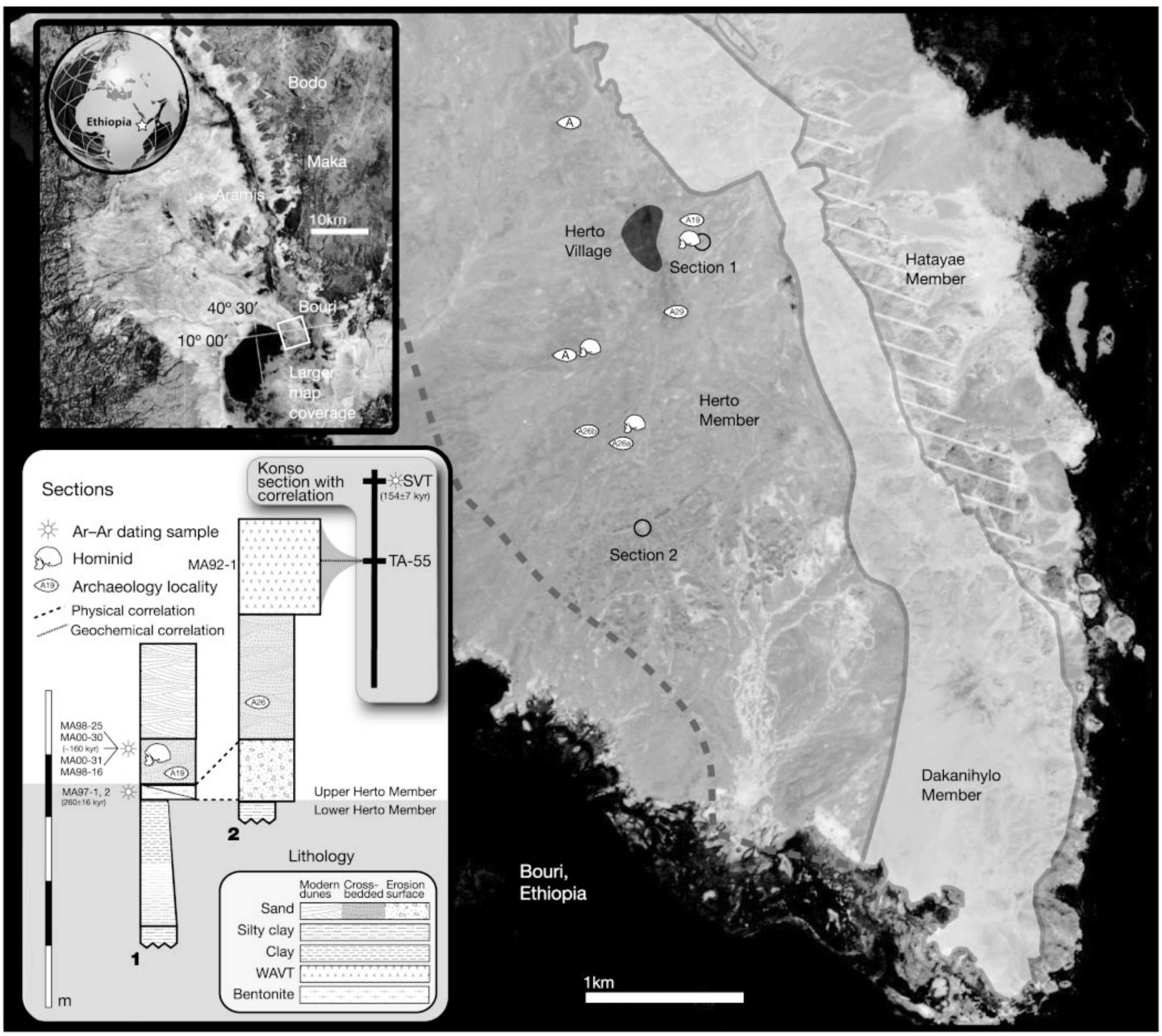

Figure 1 Geographic and stratigraphic placement of the Herto Bouri hominid fossils and archaeological artefacts. See the text for details.

artefact-bearing, semi-indurated pebble conglomerate. This unit's consolidation renders it a widespread planar marker with distinctive geomorphological expression, recognizable by its incorporation of rounded pebbles and large bentonite clasts derived from reworking of the underlying MA97-2 volcanic unit. Small gastropod shells are often present immediately above this contact. We interpret this pebble horizon as having been deposited marginal to a shallow freshwater lake. This erosional surface is immediately overlain by a volcaniclastic sandstone and gravel deposit that yielded all of the Herto hominid fossils and all of the Upper Herto Member archaeological assemblages described below. This fluviatile sand unit is variable in thickness, yellow-brown to grey, and cross-bedded, bearing abundant rolled pumices up to 15 cm in diameter. The planar pebble surface was broken in the area immediately southeast of Herto Village (Fig. 1) by syn-depositional and post-depositional faulting. Upper Herto sand deposits more than 3 m thick are preserved against the fault scarps.

Geochronological control over Upper Herto Member artefacts and fossils has been achieved through the integration of lithostratigraphy, tephrostratigraphy and radioisotopic dating. The maximum age for the sandstone unit containing the Upper Herto artefacts and fossils is defined by $^{40}Ar/^{39}Ar$ ratio analyses of embedded pumices and obsidian clasts sampled from the same unit across more than 500 m (see Fig. 1 and Supplementary Information). Anorthoclase grains from two pumice clasts (MA98-25 and MA00-30) yielded plateau ages for incrementally heated multigrain samples of 163 ± 3 and 162 ± 3 kyr, respectively. Indistinguishable (although less precise) ages were obtained by total fusion analysis of single crystals. Multigrain incremental heating analysis of a third pumice clast (MA00-31) sampled from the same sandstone unit yielded sanidine with a plateau age of 226 ± 2 kyr. Two obsidian clasts from the same sands were also analysed by incremental laser heating. One (MA98-16B) yielded a well-defined plateau age at 160 ± 2 kyr.

The preponderance of pumice and obsidian with indistinguishable ages of about 160 kyr indicates that these age maxima might be close to the actual time of deposition of this fossiliferous unit. Independent confirmation of these radioisotopic determinations on

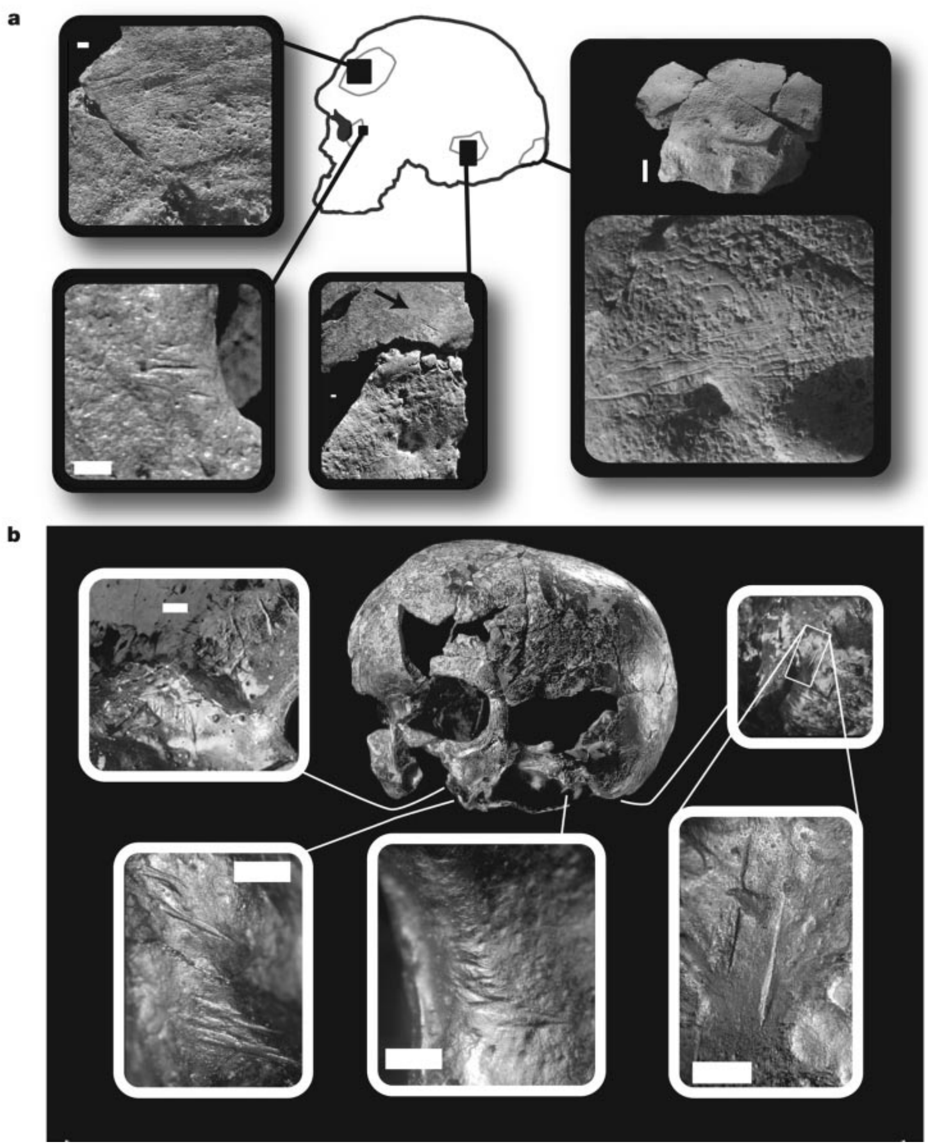

Figure 2 Cultural modification of the Herto adult and child crania. **a**, BOU-VP-16/2 adult cranial fragments to show selected defleshing cutmarks on the left zygomatic and parietal asterionic corner, and other more superficial artificial scoring above the left temporal line and across the occipital plane. **b**, BOU-VP-16/5 child's cranium with defleshing cutmarks on the left sphenoid, and right and left temporals, and post-mortem polish on the parietals. See the text for details. Vertical scale bar, 1 cm; horizontal scale bars, 1 mm.

the embedded volcanics was attempted by thermoluminescence dating, which proved unreliable. Uranium–thorium disequilibrium analyses of fossil bone were inconclusive.

A few hundred metres southeast and southwest of the hominid discoveries (Fig. 1), the Upper Herto fossiliferous deposits are capped by the WAVT tuff (MA92-1), at least 1.65 m thick, which is a very fine vitric ash with up to 10% finely fragmented crystals of quartz and feldspar (see Supplementary Information). The minimum age for the Herto archaeological occurrences is thus constrained by the overlying WAVT, which has resisted accurate $^{40}Ar/^{39}Ar$ dating because of contamination by older crystals. However, major element compositions of individual glass shards determined by electron probe microanalysis, and major and trace element compositions (Supplementary Table 2) of purified bulk glass separates by direct-current argon plasma spectrometry, provide a secure correlation of the Herto Bouri WAVT (sample MA92-1) with an unnamed Pleistocene tuff (sample TA-55) from the Konso region of southern Ethiopia[5]. The Konso Silver Tuff (sample TG 120) found 6 m above this WAVT-correlative has been dated at 154 ± 7 kyr ago, on the basis of the weighted mean of 14 individual $^{40}Ar/^{39}Ar$ laser fusion analyses of sanidine crystals (see Supplementary Information). Eleven xenocrysts with ages more than 7 s.d. from the mean are confidently resolved from the juvenile population. On the basis of the combined stratigraphic, geochemical and radioisotopic evidence, the Upper Herto archaeological and palaeontological remains are therefore securely constrained to be between 160 ± 2 and 154 ± 7 kyr old. They are thus late Middle Pleistocene in age, a placement entirely consistent with the palaeontological and archaeological evidence.

Chronometric placement of the Herto discoveries is significant because the accurate dating of faunas and artefacts of many sites of this general antiquity in Pleistocene Africa has proved notoriously difficult[6]. Consequently, the transition to anatomical modernity in African hominid populations has proved difficult to document because of the lack of chronological control over the widely scattered hominid fossils that are often singular and fragmentary[7]. Compounding this problem is the developing consensus that the transition between the Acheulean and MSA technocomplexes in Africa was both temporally and spatially complex, involving blades, points and Levallois elements in late Acheulean assemblages, and including bifaces persisting in assemblages that would otherwise be termed MSA[8,9]. The antiquity and geographic position of the Herto discoveries in the Horn of Africa therefore advance our understanding of both technological and anatomical change.

Upper Herto Member archaeological assemblages have been observed across more than 5 km of modern landscape. Artefacts and stratigraphically associated fossils are particularly abundant in the fluviatile deposits immediately atop the widespread erosional surface defining the Lower to Upper Herto submember boundary as described above. The bulk of the vertebrate fauna also comes from this widespread sand unit and includes a derived extinct bovine, *Kobus* species, *Thryonomys*, *Hippopotamus*, *Equus* and *Connochaetes*. These taxa indicate the proximity of both aquatic and grassland habitats.

The Upper Herto archaeological assemblages described here were recovered mainly from controlled surface collections of representative lithic artefacts at the following localities (all handaxes, flake tools, cores, flakes and blades were collected on sublocalities designated at each archaeological occurrence; see Fig. 1 and Supplementary Table 3): BOU-A19 (71 artefacts from sublocalities A, C–G, H–N; total 10,100 m^2); BOU-A26 (331 artefacts from sublocalities A–C; total 777 m^2); and BOU-A29 (194 artefacts from 5,000 m^2). All of these surface assemblages were judged to derive from the lower 1 m of the hominid-bearing sand unit described above and were recovered from erosional exposure of *in situ* artefacts, or from controlled surface collections made on the basis of preservational characters, adhering matrix and/or geomorphological disposition. In addition, to control these surface collections further with additional *in situ* materials, we undertook excavations at sublocality BOU-A19B, the site of discovery of a cutmarked hippopotamus cranium. From this excavation we recovered 29 lithic artefacts interbedded with a rich faunal assemblage from less than 20 cm of archaeological deposit excavated across 33 m^2. Another excavation at the location (BOU-A19H) of the *in situ* discovery of the complete adult hominid cranium described below revealed 15 artefacts from less than 20 cm of archaeological deposit with abundant modified faunal remains, excavated across 41.5 m^2. Excavated remains differed in no significant manner from the controlled surface collections, and there was no evidence of any contamination from younger deposits (only thin aeolian dunes now cover the sampled unit in the area).

The combined Upper Herto archaeological assemblages vary spatially in their lithological and typological contents. The Levallois method is well represented across samples. Levallois and smallish Levallois flakes and points normally associated with the African MSA are present, as are Acheulean cleavers and other bifaces. All these tool types are represented by examples found *in situ* in the hominid-bearing sand unit. Similar assemblages are traditionally classified as final or 'transitional' Acheulean.

Controlled surface collection and excavation at Upper Herto localities BOU-A19, BOU-A26 and BOU-A29 yielded a pooled lithic assemblage of 640 analysed artefacts (see Supplementary Information) adequate to characterize the industry that is stratigraphically contemporary with the hominid fossils. Whereas the pooled assemblage assessed here is adequate to characterize the Upper Herto Member archaeology qualitatively, additional excavations will be required for a fuller quantitative analysis of the lithic materials. Even at this early stage of investigation it is evident that handaxes and picks are rare (less than 5% of flaked implements collected), as are blades (less than 1%). The rarity of handaxe preparation flakes among the collected lithics indicates that these tools may have been made elsewhere. Raw material is predominantly fine-grained basalt, except for points and blades, which were made mostly on obsidian. Cryptocrystalline rocks used for some scrapers are rarer, comprising 5% of the total retouched lithics.

The Levallois method is well represented in the pooled assemblage and was used frequently in the production of the handaxes and cleavers. Evidence of Levallois method is also observed on 48 flakes, blades and points. Of the 63 tools on flakes, 9 were made on Levallois flakes. Preparation was usually radial centripetal. Flakes are mostly elliptical with flat section, with platforms almost always faceted convex. They are typologically 'chapeaux de gendarme' and 'en aile d'oiseau', with a platform angle always between 90° and 95°. Of the 53 cores collected and analysed, 28 are discoid; these are probably the result of exhaustive exploitation of the Levallois cores. Blade technology is present, but rare, with only four blades (three *in situ*), all on obsidian.

The analysed 28 bifaces span a wide size range and were all made on fine-grained basalt. They are represented by ovates, elongate ovates, triangulars, cleavers, and a pick, biface scraper and biface nucleus. The 17 handaxes with ovate and elongate ovate plan forms were always made on flakes and finished with soft hammer technique. Edges are regular and show secondary edge retouching.

Of the 25 side scrapers, simple side scrapers dominate ($n = 22$), the remainder being convergent side scrapers and a double-sided scraper with biconvex edges. Most specimens show direct retouch. Fifteen end-scrapers or rabots are present, made on thick flakes that sometimes conserve cortex. The working edges are usually convex and regular, made with lamellar retouching. Most of these tools are also side scrapers; some are carinated and resemble Aurignacian types.

The technological and typological positions of the Upper Herto assemblages seem closest to Garba III at Melka Kunture, Ethiopia[10,11]. As at Herto, Garba III includes terminal Acheulean handaxes, typical Levalloisian method, and many retouched tools on flakes (side-scrapers and end-scrapers, backed knives, burins, unifacial and bifacial points). The Garba III assemblage has been considered transitional between the Acheulean and the MSA[11].

Indications at Gaddemota (Ethiopia) and Kapthurin (Kenya) are that by about 280 kyr ago, Acheulean assemblages at some African sites had incorporated new elements typical of the MSA. The demonstrably younger Herto Member assemblages, with their mix of Acheulean and MSA technological attributes and artefact forms, add complexity to this picture and confirm that the transition to the MSA in eastern Africa was not a simple or a gradual process[8,12]. The cultural mosaic across time and space probably derives from variations in geography, ecology and raw material, and other cultural variables that will require disentanglement by further research.

The Upper Herto hominids occupied the margin of a freshwater lake, and archaeological evidence from the base of this submember indicates hominid butchery of large mammal carcasses, particularly hippopotamids. Such butchery is documented for the earlier Lower Herto beds[4]. It persisted in the Upper Herto, where numerous examples of cutmarked and percussion-fractured hippopotamus and bovine remains are observable in the sand unit directly above the erosional surface. One occurrence shows abundant remains of several hippo calves, mostly newborn to a few weeks old, scattered together with butchered adults.

The basal sandstone of the Upper Herto Member yielded three hominid crania found just east of Herto village. The most intact is BOU-VP-16/1, an adult cranium with dentition found *in situ* by D. DeGusta on 27 November 1997. Its left side was partly lost owing to modern erosion, whereas its intact right side faced downwards and was preserved. The cranium was cemented in place by indurated sand lenses. Excavation demonstrated conclusively that the specimen was not intrusive. A rich archaeological horizon was encountered 25 cm below the cranium, but there was no direct archaeological association within the 60 m^2 excavation centred on the fossil. The BOU-VP-16/5 juvenile individual was a surface find made on 3 December 1997 by B. Asfaw. Adhering sand matrix shows that it was also embedded in stained sands immediately above the erosional surface. The third major hominid fossil from contemporary Upper Herto sediments was another adult (BOU-VP-16/2), this individual represented by 24 mostly vault fragments found on the surface of the erosional contact by C. Pehlevan on 27 November 1997. No hominid postcranial elements have yet been recovered from Upper Herto Member deposits.

The anatomical and evolutionary significance of the hominid crania is considered elsewhere[1]. The three primary Herto crania all bear cultural modification indicative of mortuary practice. The least modified is the more intact male individual BOU-VP-16/1, which shows a long, thin, weakly sinuous, 35-mm vertical cutmark on the anteroinferior corner of its right parietal, and a second, shorter mark surmounting the supramastoid crest of the right temporal. No other modification is visible. The second adult cranium, also a probable male, was highly fragmented and scattered after it emerged from the same sand unit. The lack of recovered dental, facial or basicranial parts indicates that it may have been embedded as a calotte. Evidence of intensive bone modification is present on 15 of its 24 recovered fragments. Some exhibit cutmarks that are probably associated with removal of soft tissue. Deep, typical defleshing cutmarks are seen on the parietals, left zygomatic, frontal and occipital (Fig. 2). More abundant but more superficial marks showing a repetitive scraping motion are present around the vault circumference, above the nuchal and temporal lines. The latter pattern of bone surface modification is almost never present in hominid or nonhuman faunal remains processed for consumption[13], and is therefore unlikely to represent evidence of utilitarian or economic behaviour.

The juvenile cranium lacks such superficial scoring marks but displays an unambiguous series of defleshing-related cutmarks on the basicranial surfaces of its sphenoid and temporal bones on both right and left sides. These fine but deep and repetitive cutmarks (Fig. 2) were made by a very sharp, probably obsidian flake edge. Their locations, dimensions and directions around the perimeter of the glenoid fossae indicate that this defleshing manipulation must have occurred after removal of the mandible. The intentional and deliberate removal of soft tissues such as basicranial vessels, nerves and muscles is therefore indicated. The specimen lacks the entire occipital region surrounding the foramen magnum, and the edges of this broken region are smooth and polished, as are the specimen's unweathered parietal surfaces.

Ethnographic and osteological evidence from several cultures documents the post-mortem manipulation and curation of human remains as part of mortuary practices[13]. For example, some New Guinean crania show cutmarks, decoration and polishing reminiscent of traces seen on the Herto hominids[14]. The earliest indications of cultural modification of hominid remains are the disarticulation-related cutmarks present on the early *Homo* specimen Stw-53 from Sterkfontein[15]. The Middle Pleistocene Bodo cranium, which is much earlier than the Herto hominids, gives the earliest evidence of non-utilitarian mortuary practice in the hominid fossil record, but the cutmarks it bears seem to be related to defleshing and not decoration[16]. The diverse bone modifications marking the three most intact Middle Awash Herto hominid crania indicate post-mortem defleshing with stone tools in the Upper Pleistocene, in an archaeological context straddling the Acheulean and MSA. Polishing and intentional scraping modifications evident on two of these crania indicate that the Upper Herto hominids may have manipulated the crania of their dead in mortuary practices whose dimensions, context and meaning might be revealed only by further discoveries. □

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The remarkable inefficiency of word recognition

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Do we recognize common objects by parts, or as wholes? Holistic recognition would be efficient, yet people detect a grating of light and dark stripes by parts. Thus efficiency falls as the number of stripes increases, in inverse proportion, as explained by probability summation among independent feature detectors[1]. It is inefficient to detect correlated components independently. But gratings are uncommon artificial stimuli that may fail to tap the full power of visual object recognition. Familiar objects become special as people become expert at judging them[2,3], possibly because the processing becomes more holistic. Letters and words were designed to be easily recognized, and, through a lifetime of reading, our visual system presumably has adapted to do this as well as it possibly can. Here we show that in identifying familiar English words, even the five most common three-letter words, observers have the handicap predicted by recognition by parts: a word is unreadable unless its letters are separately identifiable. Efficiency is inversely proportional to word length, independent of how many possible words (5, 26 or thousands) the test word is drawn from. Human performance never exceeds that attainable by strictly letter- or feature-based models. Thus, everything seen is a pattern of features. Despite our virtuosity at recognizing patterns and our expertise from reading a billion letters, we never learn to see a word as a feature; our efficiency is limited by the bottleneck of having to rigorously and independently detect simple features.

The role of components in object recognition is still mysterious[4–7]. For most objects we don't even know what the components are, but we do know that words are made of letters. Is a familiar word recognized as an image, or as a combination of individually recognized letters? Despite a century of careful study[8–16], it has never been noted that these two alternatives predict very different thresholds for identifying words. Once we have defined a few terms, you can test the predictions with your own eyes.

The strength of visual signals is traditionally specified by 'contrast', which here is the ratio of the luminance increment of the letter or word to the background luminance. However, for ideal-observer analysis it is helpful to specify 'contrast energy', which for a letter or a word is the product of squared contrast and 'ink' area. In general, contrast energy is the integral of the squared signal contrast over the extent of the stimulus. Energy matters: mathematical work on radar in the 1950s proved that the energy of a known signal completely determines its detectability in white noise[17]. 'Threshold', the border between seeing and not seeing, is defined here as the contrast or energy required by the observer to correctly identify the letter or word 64% of the time.

In Fig. 1a, the two lines of faint text have the same overall contrast energy, but differ in the way that the energy is distributed. To optimize recognition by parts, the first line gives each letter the same energy. To optimize recognition as wholes, the second line gives each word the same energy. Recognition by parts predicts that the longer words in the second line will be illegible, as you see, because there isn't enough energy per letter. Recognition as wholes predicts that all words in the second line will be equally legible, contrary to what you see. Figure 1b shows the predictions for your word threshold on blank and noisy backgrounds. The same analysis applies to both backgrounds because the observer effectively adds his or her intrinsic visual noise to the display[18].

Our recognition-as-wholes predictions are based on the ideal observer, which, given the stimulus and its statistics, achieves the best possible expected performance by choosing the most probable letter or word[17,18]. We can assess human performance on an absolute scale by defining 'efficiency' as the ratio of the ideal's threshold energy to the human observer's: the fraction of the energy used by

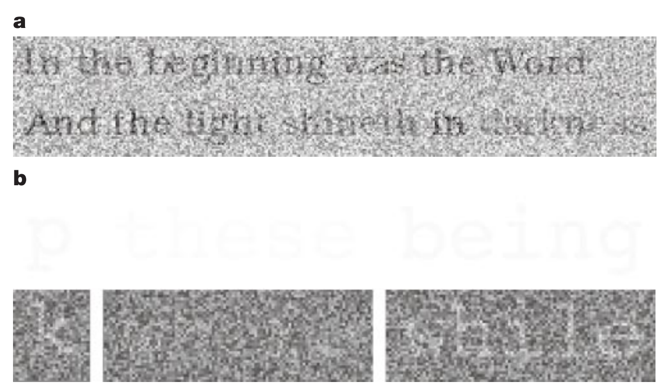

Figure 1 By letter or by word? **a**, Both lines of the quotation have the same total contrast energy. In the first, the energy is divided equally among the letters. In the second, the energy is divided equally among the words, regardless of length. In principle, at a given noise level a pattern's detectability depends only on its energy, but in the second quotation the short words pop out and the long words disappear. This word-length effect shows that human readers cannot efficiently integrate the energy across a whole word. (The quotation reads 'In the beginning was the Word … And the light shineth in darkness'.) **b**, Two predictions for the word threshold. The left column shows a letter at threshold on a uniform white background (top row) and on a noisy background (bottom row). They may take a minute to appear. The middle column shows a 5-letter word at the same energy ($1/\sqrt{5}$ the contrast), which is the threshold predicted by recognition as wholes, and the right column shows a word at 5 times the energy (the same contrast), which is the threshold predicted by recognition by parts. The words in the middle column would be identifiable if you could see words as efficiently as you see letters. (The first line reads `p`, `these`, `being`, and the second reads `k`, `?????`, `while`, where the identity of the middle word remains undisclosed.) Note: The faint lettering on a white background is at the limits of what can be rendered on the printed page. The PDF of this letter prints the figure successfully on most modern printers, especially colour printers. If in doubt, readers are urged to refer to a more robust version of Fig. 1b available as Supplementary Information, which accommodates variations in printers' rendering and readers' sensitivity.