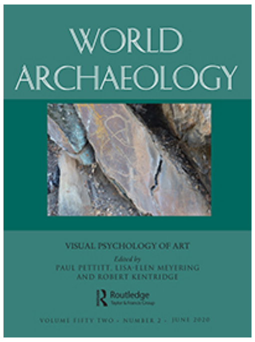

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The visual psychology of European Upper Palaeolithic figurative art: using *Bubbles* to understand outline depictions

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ABSTRACT
How have our visual brains evolved, and exactly how did this constrain the specific way that animals were depicted in Upper Palaeolithic art? Here, we test predictions derived from visual neuroscience in this field. Using the example of open-air Upper Palaeolithic rock art of Portugal's Côa Valley, we point out the frequently recurring outline strategies that past artists utilized to depict the prey animals upon which they were dependent for survival. Their depictional tendency can be mirrored onto the most visually salient anatomical aspects of these species, a finding that results from our use of a visual psychological experimental programme, called *Bubbles*. We find a remarkable correspondence between the aspects of the anatomy of horses and bison that modern participants found most helpful in successfully discriminating between the two, and those same aspects that are elaborated most in Upper Palaeolithic art. This leads us to conclude that the visual system of *Homo sapiens* drove the way that important prey species were depicted, and hence, the form of their art.

KEYWORDS
Palaeolithic; rock art; perception; visual psychology; Bubbles

Palaeolithic rock art – an art of outline

European Upper Palaeolithic figurative 'art' (~37-13 ka BP) is overwhelmingly dominated by depictions of gregarious prey animals such as horse, deer, ibex, bison and aurochsen, with a lesser component of reindeer, mammoth and rhino, and rare depictions of fish, birds, carnivores and small fur bearers. Depictions of anthropomorphs are very rare (and often contentious), and possible depictions of land-scapes, dwelling spaces or other phenomena almost non-existent. Despite this, however, it would be incorrect to characterize it as simply reflecting a preoccupation with *animals*. It has long been known that a very specific and widespread 'grammar' of exactly how these animals were portrayed played a role in the thematic and stylistic creation of art from at least the early Mid Upper Palaeolithic (Gravettian), and possibly earlier. Animals were almost always depicted in profile (side) view rather than frontal or rear; mostly in 'strict' profile – that is, with two legs and one horn – although sometimes the so-called *twisted perspective* was used to depict two horns on an otherwise strictly in-profile animal. Artists depicted animals through contoured lines, accentuating their dorsal lines in particular, exaggerating specific features such as horns, antlers, shoulder humps and manes, and conversely, often omitting elements such as hooves, facial features and other internal features such as pelage or musculature. Instances of depth perception are effectively non-existent, and as such it is commonly observable that the size of an

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ibex, for example, equates to that of a horse on the same panel, a similarity in size that of course does not actually exist. Rather, figures interact with the topography of cave walls irrespective of their size, and incorporate elements of light, shadow and physical volume into their own volume. While specifics of style, theme and production vary over the course of the ~25,000 years of its duration, these are the essentials of European Upper Palaeolithic figurative visual culture (Aujoulat 2005; Bahn 2016; Fritz, Wills, and Tosello 2016; Groenen 2000; Guthrie 2006; Janik 2020; Leroi-Gourhan 1992; Lorblanchet 1995; Straus 1987; Vialou 1998).

Here, we are concerned with how the techniques of modern visual psychological research can be used to elucidate why Upper Palaeolithic depictions were created in particular ways, and why these ways were redundant, i.e. restricted to a small number of possibilities out of a far larger set of possibilities. Why was the subject matter – and particularly the way of depicting – so repeatedly similar over such a vast time period? We draw on Upper Palaeolithic open-air rock art from Portugal's Côa Valley to illustrate the points we raise here (see examples in Figure 1). The Côa Valley, through which the Douro and its left-bank tributary, the Côa river runs, is situated in the North East of Portugal. Since 1994, thousands of rock engravings of demonstrably Upper Palaeolithic age have been discovered and excavated from a ~ 15 km stretch of the river valley, with more being found each year (Aubry et al. 2020). In many cases the engraved and pecked art has been covered and preserved by sedimentary layers containing archaeological materials of Late Upper Palaeolithic (Solutrean and Late Magdalenian) date. In some cases these layers directly abut the art, e.g. at the site of Fariseu. As a result, the Upper Palaeolithic age range of the valley's art has now been firmly established based on radiometric dating of sediments which cover the art and therefore form a minimum age for it. As a result of this, independently verified by thematic and stylistic comparison with securely dated portable art from elsewhere, it is generally agreed that the art spans the period ~24,000–14,500 Before Present; culturally from the Late Gravettian/early Solutrean to the Late Magdalenian inclusive (Zilhão 1995; Valladas et al. 2001; Aubry et al. 2002).

Of a total of 1117 figurative rock engravings from the area that are currently well-studied and documented, only a small number of motifs appear in a state that cannot be termed a *profile view*. Unsurprisingly, these few exceptions are depictions of anthropomorphs, which face the audience in a portrait-style manner. It is striking that examples of rock art animals from around the world also display a similar trait of depicting animals in profile as we find at Côa; e.g. animal outlines on a cliff face in Yunnan Province, southwest China (Taçon et al. 2010); animal depictions in the Dampier archipelago, southern Australia (Watchman 1993; Mulvaney 2013); contoured bovids from Qurta I in Egypt (Huyge et al. 2007); and the recently re-emerging outlines of babirusas ('pig-deers') in

Figure 1. Rock art examples from the Côa Valley (left Quinta da Barca; right Penascosa, Photographs by Meyering, 2018).

Sulawesi, Indonesia (Van Heekeren 1952; Aubert *et al*. 2014; Hayes and Van Den Bergh 2018). All these instances suggest that this particular profile view 'grammar' for depicting animals can be seen as a pan-global phenomenon.

Several scholars have previously addressed this pervasiveness of art-making technique over vast spatial distance by drawing on evidence from both disciplines of archaeology and psychology. More specifically, the recent decade has seen rock art specialists turn to aspects of neuroscience and the psychology of vision to try and explain why the art adopts the characteristic outlined forms that are so ubiquitous. Kennedy and Silver (1974, 313) recognized a relatedness between graphic strategies in the Antipodes, claiming that 'lines can be "surrogates" for what we may call the basic sources of optical structure'. Halverson (1992) pointed to the pan-global occurrence of in-profile rock art animals and illustrated how silhouettes can reinforce the external contours of animals by pointing to a clear demarcation between the Gestaltian principles of the figure and the ground, and the use of this demarcation in art creation.

Perceptual psychology was further employed in conjunction with rock art studies by scholars such as Deregowski (1989) and Hudson (1998). Once neuroscientists were able to explain the link between the visual brain and its processing of visual information Hodgson (2000, 2013), Dobrez and Dobrez (2013) and Watson (2011, 2012), amongst others, appraised the importance of what neuroscientific processes – our evolutionary constraints and the developmental stages of our cognitive system – could reveal about the commonalities of the earliest art. This suggested that the apparently universal contouring and profiling of animals could be explained in terms of the constraints of our own visual capacities, i.e. that 'such pervasiveness derives from the way the visual brain functions' (Hodgson (2013: 1: see also Hodgson and Helvenston 2006). We specifically test this prediction here, investigating how the functions of the visual brain correlate with the specific form that rock art takes. We place emphasis on how the visual brain will 'focus in' specifically on the most salient (most diagnostic) parts of the animals of concern (in this case aurochsen and horses). We deploy a computer-based programme – *Bubbles* – originally developed for examining facial expressions, to compare an experimentally-derived set of images created by participants to the real rock art motifs. Does the rock art conform to the hard-wired visual preferences of humans we can establish experimentally, and vice versa?

One alternative, ubiquitous explanation would be that the constant 'preoccupation' of being a hunter-gatherer dependent for survival largely on the hunting of large, gregarious herbivores. In such circumstances it is no surprise that for Palaeolithic hunter-gatherers such animals were good to think with (Lévi-Strauss 1962, 89). However, this socio-economic argument only goes as far as explaining *why* animal depictions predominate in the rock art repertoire of Palaeolithic hunter-gatherers. It does not account for the reasons as to why animals were depicted and constructed in a similar outlined manner across the continents. Hodgson and Watson (2015, 782) concur that this 'does not (...) imply that humans are pre-programmed to depict animals in a stereotyped way, rather this can be overridden by socio-cultural input'. So far, therefore, discussions on the subject have been relatively limited, and could be characterized as concluding simply that 'the dominance of animals is brain, the rest is culture'. We believe that the apparently pan-global appearance of similar conventions of animal depiction requires greater understanding.

Not only are animal depictions overwhelmingly portrayed in profile view, but many are not even outlined in full. It seems as if artists availed themselves of visual strategies such as the Gestalt's *Law of Closure* in order for their depictions to appear as full and complete as possible without having to engrave all components of the animals (see Hodgson and Pettitt 2018). Investigations from the case study of rock art motifs of the Côa Valley demonstrate that the majority of animal depictions are indeed incomplete (n = 687; 62% of currently known images) with only 38% of all other animal figures featuring a complete outlined form n = 430; 38%). Upon inspecting and categorizing hundreds of such motifs, one is able to appreciate that the collective depiction of animals in Palaeolithic art essentially involved the process of simplifying what is seen. In order to achieve this, animals were reduced to their most essential core lines and salient features that were most useful for their swift identification in the field, e.g. horns. Intriguingly, thanks to the preservation of such minimal lines, modern observers are still able to identify ('resolve') exactly which species are being represented. A living being is reduced to a minimal representation, yet is still sufficiently outlined to make it recognizable, both as an animal, and as a specific taxon. We are still often able to pinpoint, even down to a specific gender, the species depicted on the rocks. We explore this underlying conceptualization here, testing it on two distinct animal taxa: which lines or which features are diagnostic cues for an animal to be distinguished as either a bison or a horse? Which lines need to be switched, which features need accentuating in order for us, as observers, to distinguish between completely different species, and how is this reflected in art?

Bubbles – identifying the saliency of animal forms

In search of answers for this seemingly universal contouring and profiling of animals, we have adapted a visual psychological experiment, originally developed by visual psychologists to explore the recognition of human facial features, to investigate Upper Palaeolithic art. Our experiment was constructed to query the saliency of different anatomical parts of our chosen animal taxa and to search for a possible resemblance between these and the saliency of parts exaggerated in rock art depictions (an aspect of what Palaeolithic art specialists call 'style'). When we apply this to Upper Palaeolithic art, we can question whether perceptual factors explain why so many images are drawn in the way they are. The technique we use, simply called *Bubbles*, was first developed by Gosselin and Schyns (2001) and presents sparsely populated images as computerized stimuli to participants so as to determine the diagnostic visual information of the presented categorization tasks. It reveals exactly what information is exploited by human observers when making judgements/interpretations of visual images, and is, therefore, especially helpful in identifying the extent of perceiving real and illusory contours within the presented stimuli. The key for processing stimuli such as the categorization of specific scenes, faces or objects lies in the type and amount of input of visual information. *Bubbles* assigns 'the credit of human categorisation performance to specific visual information' (Gosselin and Schyns 2001, 2261).

The method addresses the question of exactly which stimuli regions aid a system in giving the correct response (put more simply, what parts of an animal's outline most frequently lead to correct identification of that animal's taxon), as opposed to the question of which regions influence the systems responses in any way at all. For the first implementation of *Bubbles*, Gosselin and Schyns (2001) instructed their experimental participants to discriminate between happy or neutral human faces in photographs. Only specific parts of the faces were presented to the observers, with most of the extent of the face covered by a grey mask and only a small proportion of the stimulus revealed through small round openings or snapshots, hence '*bubbles*'. Through this, the experimenters aimed to test whether small sections of the whole were able to yield successful discriminations between the two stimulus types. Although the original *Bubbles* software has been trialled with facial recognition tasks based on gender, expression and identity, and also on natural scenes (McCotter et al. 2005) and infant perception (Humphreys et al. 2006), the original authors were open to the possibilities that 'the principle of *Bubbles* should generalise to other objects and scenes'. We have taken up this challenge, presenting here the results of our use of *Bubbles* based on two different types of prey animals that are dominant in the Côa art, horse and bison.

Detection versus discrimination

From a perceptual point of view, there are two main tasks that a Palaeolithic hunter has to excel at: first, to be able to *detect* prey species in the landscape, and secondly, to be able to *discriminate* between different types of prey species (i.e. to identify them to a specific taxon). Applicably, we will therefore test whether the minimal amount of information needed for the discrimination of particular animals coincides with the dominant or emphasized features that we see in the rock art. The *detection* ability of primates is critical in ensuring their survival when on the lookout for potential danger (Caro 2005). Before responding to potential threats, however, they need to detect them first by means of the 'capture of attention', in other words, their attention needs to shift swiftly towards the potential danger (see Cronin 2005; Yorzinski and Platt 2014). In fact, Coss (2003) and Isbell (2006) regard it as likely that our extended evolutionary sympatry with various predators specifically shaped our perceptual system to respond to dangerous animals in a rapid manner. New, Cosmides, and Tooby (2007) found that participants exhibit a superior performance in detecting animate objects (i.e. animals) compared with inanimate objects (i.e. vehicles, even when they are in motion). They concluded that 'the human attention system evolved category-specific selection criteria [specifically] to monitor animals' (New, Cosmides, and Tooby 2007: 16, 604). Accordingly, many researchers have studied participant behaviours when subjecting them to visual-search tasks involving threatening and non-threatening stimuli. The ability of *discrimination*, in other words for humans to be able to distinguish between different species of prey, is always predicated upon focal attention (i.e. prey needs to be fixated in order to be identified). In an early experiment by Sagi and Julesz (1985), the authors realized that observers were able to discriminate between stimuli only once they achieved focal attention on a fixated target. Their experiments showed that prey species will only be discriminated once they are fixated; once the eyes are fully on the target, so to speak. Speaking of target fixation, the frequently adopted *visual salience model* by Itti, Koch, and Niebur (1998) was the first to map, using eye-tracking equipment and fixation patterns, areas of particularly strong visual salience in a so-called *saliency map*. A saliency map can be likened to a heat map with red (hot) areas classed as those which are particularly noticeable or detectable within a scene and blue (cold) areas not as noticeable/salient. As such, so-called 'activation spots' illustrate where the eyes fixate to most in any given stimulus. Taking inspiration from Itti *et al.*´s work, we constructed the following experiment to identify the areas of horse and bison to which the human gaze is primarily fixated, and to and to see if the areas identified match up with the recurring features engraved into rock.

Bubbles methodology

Participants

Seventeen individuals (5 males, 12 females) participated in this experiment, all of whom had normal or corrected-to-normal eyesight and were, at the time, undergraduate students at Durham University. The experiment ran over three years, and adhered to the university's ethical practice of anonymization. All of the participants were familiar with horses (and one regularly interacted with them); by contrast, none was familiar with bison. This is a start; we acknowledge that in future we need to use larger numbers and a greater variety of participants, such as those who are particularly familiar with the rearing of horses and/or bison, long-range (binocular) observation of wildlife, or even those well-versed in the hunting of large prey animals. Nevertheless, the total of seventeen participants tested during this first instigation of the experiment make this initial study a statistically valid sample size.

Are we like them?

At this point, readers may be forgiven for thinking that the working of the brain and the visual system will have been considerably different from ours during the times that Upper Palaeolithic artists were creating their works, be it due to either cultural or evolutionary causes. Instead of testing high-level aspects of vision (determining the meaning and wider impact of art in question), it is important to note that the more fundamental, low-level vision aspects that we put to the test here (detecting stimulus, discriminating between different types of animals, establishing viewing patterns and directions), are known not to have changed since the art was created. The advent of Palaeolithic art, at least in figurative form, is generally equated with the emergence of a fully developed 'modern' *Homo sapiens* mind. Not surprisingly, several recurring patterns within the engraved rocks can be found amongst a wide sample of non-literate societies. Their rock art follows a 'basic logic' by providing us with a comprehensive expression of the fundamentals of the human cognitive system (see Chippindale and Nash 2004; Anati 2004; Pettitt 2016). Surviving rock art assemblages provide invaluable sources for understanding human behaviour and the human mind since the origins of our own species, with evidence of artistic capabilities extending considerably further back (cf. Hoffmann et al. 2018). On the basis of the justifiable assumption that the neurological structure of the brain will not have changed from the times that Upper Palaeolithic artists were at work until now, it is therefore possible to investigate the ways in which art was made and perceived at the time. Albeit there are factors such as modern eurocentric biases, changes in contextual environments and the aforementioned 'subjective' knowledge and experiences individuals bring, that need bearing in mind.

Stimulus generation and selection

The selected stimuli for this study comprises images of real-life animals mimicking the attitudes of those species of animals engraved on the rock surfaces of the Côa Valley. For the participants' trials, these took the form of two separate photographs; one of a bison and one of a Przewalski's horse, both taken by us in the Scottish Highlands. These two species were chosen since they possess great prominence amongst the rock art repertoire of the Côa Valley and elsewhere in Palaeolithic art. Their selection was also dependent on accessibility to photograph first hand (one reason why we did not select as stimuli another species commonly-depicted in the Upper Palaeolithic, the now-extinct aurochs). *Bubbles* operates by randomly sampling information in a stimulus space while observers attempt to classify the sampled information (Gosselin and Schyns 2002). During the procedure for our experiment, the target image of both bison and horse was continuously presented to participants in random order. These presentations are interleaved with presentations of visual noise between individual detection tasks. Stimuli are presented through a mid-grey mask which reveals only a portion of the underlying entirety of the animal, i.e. the small (bubbles) openings, also called Gaussian windows. These are, in line with Gaussian geometry, kept smooth and symmetrical (Marr and Poggio 1979; Chauvin et al. 2005). Bubbles appear in randomized positions on and around the outline of the images, and in randomized order on the screen. Animal stimuli are also 'flipped', so that the animals point either to the left or the right. Furthermore, depending on how well a participant performs during the trials, the openings of the bubbles adjust in size, either becoming larger (if frequently answered incorrectly) or smaller (if performance is kept up) – a process called titration.

Priming and practicing

Prior to the categorization task, participants were instructed to familiarize themselves with a set of four different species (horse, aurochs, deer, ibex) that commonly occur in the Upper Palaeolithic art and archaeofaunas of Portugal (selected based on their respective frequencies). By so doing we were able to refresh each participant's perception of these different species; two were included which did not eventually feature in the experiment, in order to avoid possible selection bias. Participants were then asked to complete a practice session in order to familiarize themselves with the experimental process, prior to commencing blocks of practice trials. Each observer repeated a practice run of a maximum of 20 trials (i.e. 20 bubbles). Once they felt that they could perform the task smoothly, the practice session ended. The actual task used the same stimulus. Practice cycles not only ensure familiarity with the software and viewing task, but also signals to the experimenters (us) that the respondents are able to accurately use the response mechanism.

Task responses

The basic task of the observer was to signal if a specific target is present in each trial or not. During the task procedure, each participating observer was instructed to press differently labelled keys for either horse (1) or bison (2) on a keyboard depending on what the target animal they believed the bubble was revealing. We present an example of a presented stimulus in Figure 2, taken during the task procedure, and which shows a horse head pointing towards the right as seen through a Gaussian aperture (bubble). In this instance, if detecting correctly, participants would press '1' for 'Horse'. Once a key was pressed, the stimulus disappears, resulting in a mid-grey mask, followed by the next bubble. The greater the accumulation of correct identifications for this bubble (in this case, number 1s) results in the area getting hotter/ redder on the resulting graphic.

Figure 2. The presented stimulus, on the left our set up 'behind the scenes' showing a bison, on the right depicting a 'participant view' Gaussian bubble of a horse head.

Limitations

Apart from some procedural limitations with the software (see, for example, 'Troubles with Bubbles' [Murray and Gold 2004] and 'No troubles with Bubbles' [Gosselin and Schyns 2004]) which have largely been rectified with the current version we employed, it should be noted that we are currently utilizing images of animals in profile, yet for future iterations of testing, more animal photographs, showing different species, and all from different angles and distances, will need to be fed into the system. Of course when testing how people are able to detect and distinguish between different animals in the actual landscape, animals rarely present themselves only in convenient profile view. Animals are mobile, often make unpredictable movements, and thus are viewed from all sorts of different angles, which we need to address in future deployment of *Bubbles*. What is useful, however, about this current adaptation of *Bubbles* with the testing of only strict profile views, is that the overwhelming majority of Upper Palaeolithic art at Côa and elsewhere also corresponds to this view. Hence, our current iteration of *Bubbles* is able to shed light on the importance and saliency of this fundamental stance, and successors will be able to delve into the idiosyncrasies of the more nuanced animal poses.

Experimental results

We present our results in a two-step manner: **(1)** The generation of classification data based on participant hit and miss rates. **(2)** The comparison of images from step one with Côa Valley rock art.

On average, testing lasted about 2.25 hours per observer, including the prior participant briefing and priming. The testing of each participant took place over one day, but not all participants were tested on the same day. After practicing, participants, in each student year, undertook three blocks of 100 trials/ bubbles each. The stimulus duration for participants was set to two seconds for each block of 100 trials. The *Bubbles* version for participants in year 1 formed the pilot study to improve upon for real trials in year 2 and 3. Blocks were performed on the basis of stored titration 'memory', with the software feeding the next trial the same bubble size as was stopped on within the previous block. The first block of trials was started with the same initial bubble size for each participant. Disregarding the trials during practice rounds, a total of 3600 trials have been performed; 300 per observer. The test run in year 1 amounted to 1500 trials, yet as an initial pilot, it did not take bubble titrations into consideration.

Constructing classification images

Participants have only one way to score successfully in any given trial, namely, to detect the correct animal species revealed in bubbles amongst the background pattern of noise. Because of this, the analysis of the observers' responses is relatively easy to visualize. Readers can think of the analysis process, which goes on behind the scenes of a participant taking these tasks, as a set of binary numbers, i.e. 0 and 1 for either a successful detection ('hit') or an unsuccessful detection ('miss'). Through this, the areas of the species that are most critical for their detection can be identified, in the form of a so-called *classification image* (a 'Cimage' see e.g. Figure 3, computed according to the methods of Smith et al. 2008 and Chauvin et al. 2005). The *Bubbles* technique is set up so that after sufficiently numerous trials, the stimulus space is exhaustively and uniformly sampled (Gosselin and Schyns 2001, 2002). From this unbiased sampling strategy, one can estimate the information biases of observers by computing how each information sample can independently determine categorization performance. Samples giving rise to significantly higher performance are called the 'diagnostic' regions of the input (such as the eyes within a face in gender recognition or, here, (foreshadowing) the horns of a bison in species discrimination). Given that

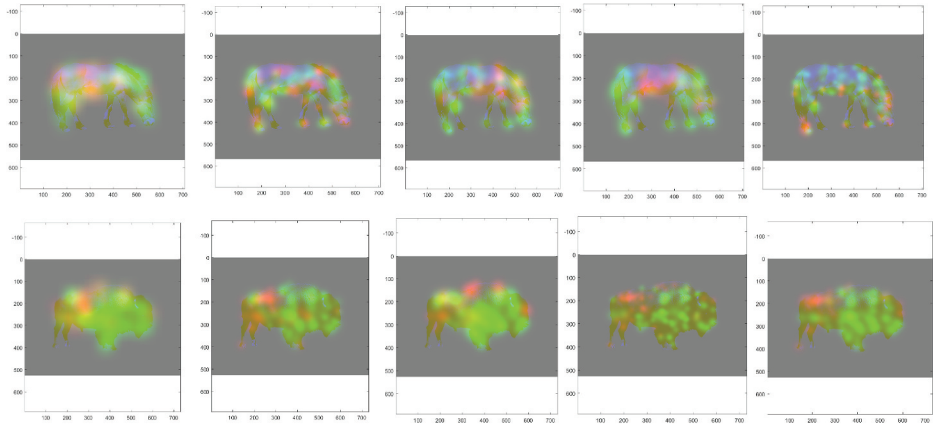

Figure 3. Selection of classification images by five of our participants. The top row represents horses, the bottom row bison. Red areas indicate 'misses', green areas indicate 'hits'.

participants underwent 100 iterations of *Bubbles* in just one block, we can be sure that certainty of space exhaustion has been provided, i.e. that we can be confident in the validity of the results.

Interpreting the classification images

The resulting classification images are able to highlight intriguing results. Both animal stimuli will be taken at face-value before applying their visual salience onto resemblances within rock art. This allows for an unbiased consideration, which does not allow for cherry-picking of green 'hit' areas to areas heightened in the rock art. Overall, the occurrence of hits and misses in various regions of the animals under scrutiny reveals that not all animal parts are equally detectable (see Figure 3).

Through the assessment of all bodily areas, we can investigate more closely which areas are consistently discriminable. All classification images have been combined and the animals' primary regions split and shaded according to their averaged classification counts. It is important to note that the results have been translated onto empty horse and bison canvasses in order to avoid potential biases arising from image-based features and to make it more translatable onto rock art features later on. We show the results in Figure 4.

In reading Figure 4 from top to bottom we are able to reveal the most salient parts of the animals, i.e. those that most consistently yielded positive classification counts. Our results clearly reveal major areas of saliency within the classification images, as seen in stage 3 and 4. When looking at the diagnostic information that participants identified in horses, **a clear tendency of correct classification alongside the upper and frontal parts of the animal's outline** can be noted. It seems persistently easier for participants to identify horse features when the bubble presents parts of the outer edges of the animal, particularly the dorsal line, head and chest (represented in green). From the positive categorization alone (IV), an outline of an animal can be identified. From collating the data of the classification images of horses, participants' responses were a lot more varied than those extracted from bison CI's. An intriguing feature in the positive CI's of horses is that major parts of the mane were often misclassified. This means that when shown a bubble over parts of the horse's mane, the participants often pressed bison. Whilst the area of the ears is diagnostic for horses and, it appears, the area directly behind the ears, an extended mane was often confused as belonging to

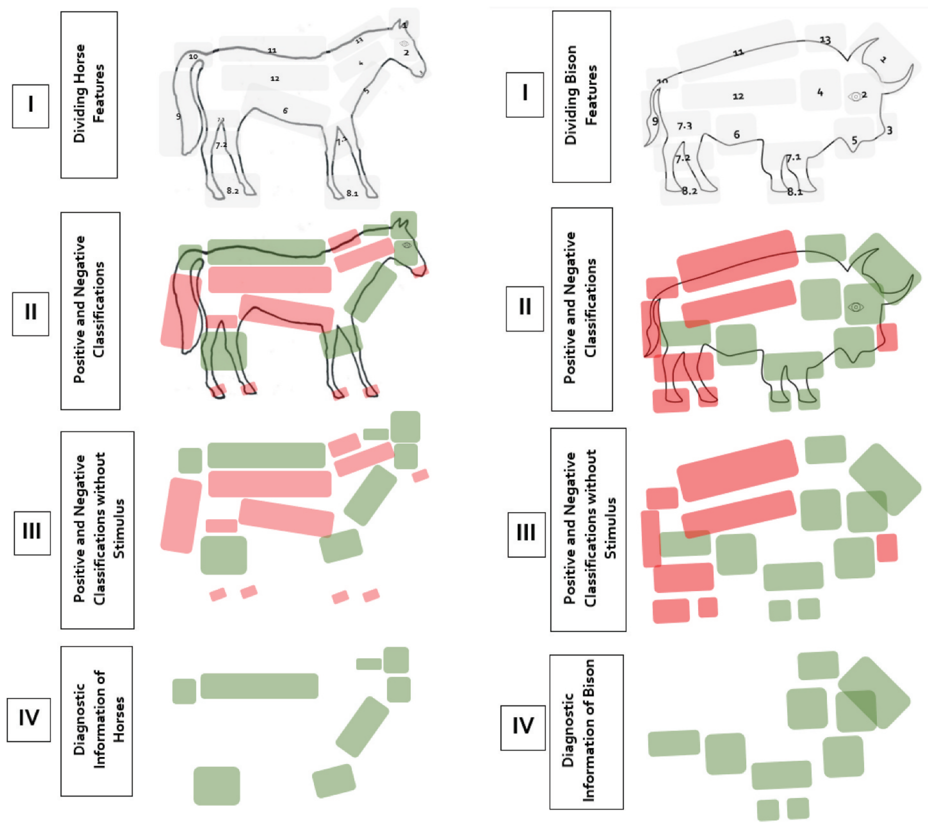

Figure 4. Collage of hit count progressions for the horse (left) and bison (right) stimulus. The red areas account for the negative classifications, the green for positive classifications.

a bison. Interestingly, the extended back of the horse was largely positively classified; the similarity of this sinuous line to its counterpart in rock art will be disclosed below. Upon inspecting the bison classification patterns, **a trend towards the protomos (the head, inclusive of the shoulder hump) and the ventral line is notable**. Furthermore, it appears that, particularly with the case of the bison stimulus, participants showed difficulty in generating successful hit rates when it came to internal details of the torso.

Conversely, the data can also be approached from another point of view. Understanding a participant's 'miss' rates on one animal and applying this understanding onto how 'miss' rates manifest themselves in the other stimulus within the same block is just as illuminating as identifying their successes. The fact that participants consistently struggled to distinguish whether they are seeing a horse or a bison when they were presented with bubbles over the inside of either animal, strongly suggests that these regions are notoriously difficult to interpret (remembering that as photographs the interior of the animals still contained potentially identifiable features such as pelage and musculature). It is nevertheless clear that a largely uniform bubble, as is the case for parts of the torso, with no identifying edges that would otherwise give its character away, largely yields a negative response, i.e. one where the respondent would 'guess' wrongly. The same goes for bubbles that display features that are similar across species, such as the display of hooves, the muzzle/snout area within both CI's or even the bushy end of tails. While we discuss the correspondence of our results with the actual art in more detail below, we note here that the result that the feet of the two taxa are not easily distinguishable corresponds to what we find on the Côa's rock surfaces (or rather what is not to be found). Participants were equally likely to 'guess' whether feet-featuring bubbles correspond to bison or horses; this reduction to a reliance on guesswork could account for the fact that feet are overwhelmingly missing from animals in rock art. All of these factors suggest that **the key to differentiation lies in the factors that make these animals distinct from each other, i.e. unique**. These features are clearly the hump and horns, and the characterizing area of thicker coat towards the head for bison, and the pointed ears, long faces and sinuous dorsal line for horses. Participants' responses throughout all of the blocks of trials confirmed that the *Bubbles* technique is, therefore, able to isolate diagnostic information in an animal discrimination task. Overall, the most salient features that are exploited during the discrimination of animal types surround animal outlines and are particularly concentrated around the protomos areas of both species.

Matching up the classification images with rock art features

Now, we test our resulting classification images against the art of the Côa Valley. If, indeed, depictions of animals in Palaeolithic art resemble their classification images, this may explain why only isolated parts of animals were typically depicted in order to stand for the whole (*pars pro toto*). Largely then, it will reveal that the specifics of rock art forms can be attributed to how the human brain processes and discriminates visual information. Hence, the entire animal masks used earlier are modified to show the positive classification areas, making it easier for subsequent comparison with rock art features (Figure 5):

The horse image was divided into two alternatives, one displaying the diagnostic information as revealed in the classification images and one accounting for the fact that the white colouration on the horse's legs in this particular stimulus used for the software likely made participants choose the animal colour and not the form itself. This throws up an interesting question on how artists will have handled the notation of colouration, such as changes in seasonal fur change or as is visible in the stimulus input, random spots of colour on the animal. Broadly speaking, it is possible to deduce that the foremost defining feature of the Côa Valley's rock art, namely that of depicting animals in outline, is also mirrored in participants' hit counts of visual saliency within the same regions. The resulting classification images strikingly do, in fact, resemble Upper Palaeolithic rock art imagery. A more nuanced look at how complete rock art depictions are in the Côa reveals further aspects of the mindsets of artists in their making process. At first sight, it seems as if both horses and aurochsen are most frequently depicted by means of full outline. Yet, when all other categories are combined, meaning those that render the animals incomplete, the pattern presented in Figure 6 is established.

It quickly becomes clear that the majority of animal depictions in the Côa region were not completed by their artists. Moreover, out of the 66% (aurochs) and 62% (horse) motifs that are deemed incomplete, 90% and 80% of motifs display all (or fewer) features represented in the overall positive classification image of these species, respectively. The concept that motifs are also displayed with fewer features than those specified in the classification images is intriguing. It strongly suggests that the artists drew on their cognitive abilities to derive the most visually salient format for their depictions, at the same time subtracting other features from that information. This gave rise to a distilled version of art creation, an extended short(er)-hand of the already cognitively derived visual shorthand.

Implications for Upper Palaeolithic art

Interestingly, the **artists seem to have reverted to using an even more stripped-down abbreviation system of engraving than would be assigned by the visual brain alone**. Even though

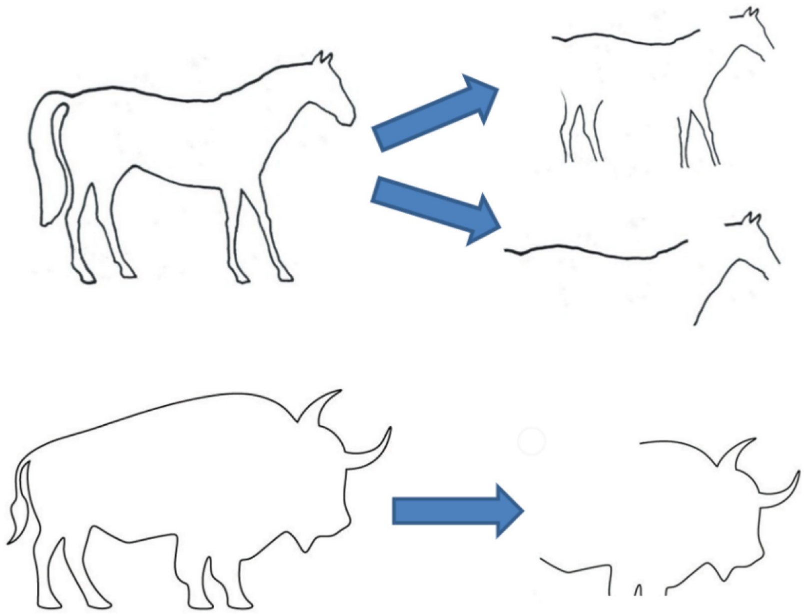

Figure 5. Graphic illustrating that the diagnostic information of bison is applicable to the features (feature-dependent) and is independent of viewpoint.

there is little doubt that the underlying human cognitive structure – assigning visual saliency – initially dictated the use of diagnostic information in the rock art, a subsequent step/reason for further rock art minimalism must have been at play at Côa. For some reason, rock artists desired to abbreviate their creations as much as possible, but still maintain the ability for discrimination; to put it another way, the design seems to have been 'how little can we depict while still getting a clear message across?' What can be inferred from the knowledge of such *shorter* short-hands? One rational explanation of this desire points to the notion of *expedience*. Rock artists clearly wanted their creations to be recognized, yet did not want to exert great amounts of time on them (particularly given the mechanical difficulty of engraving and pecking hard rock). This 'cost-benefit' system is akin to the tasks of hunters in the landscape who need to rely on the ability to swiftly locate prey species, yet also need to move on and switch to other tasks such as the identification of other incoming dangers. It is, effectively, a hair-trigger mindset.

It is worth taking a step back at this point to think about the position and perspectives of the creator/viewer of the Côa engravings. It seems as if the priority of the carver was easy legibility and immediate recognition of their creation, rather than the transmission of an accurate or detailed reproduction of it. A simple definition of what is shown is consequently created by a limited range of points and lines. Garlake (1995: 23) saw a similar pattern emerging in studying Zimbabwean art, pointing out that 'the (carvings) are intellectual *distillations* of concepts of reality' (our emphasis). Every animal seems to be reduced to its most essential characteristics, which creates an effortless immediacy of meaning through mark making. This would be a satisfying answer if there were no other rock art images that do not abide by this *minimalism* rule, which, as established earlier, is the case. Indeed, after establishing that rock art depictions seem to have been guided by visual attention, why is not all art depicted in this fashion? Why does one, time and time again, find embellished animals, complete with depictions of eyes and hooves (features that, cognitively, are very similar between species)? If the torso of the animal can essentially be

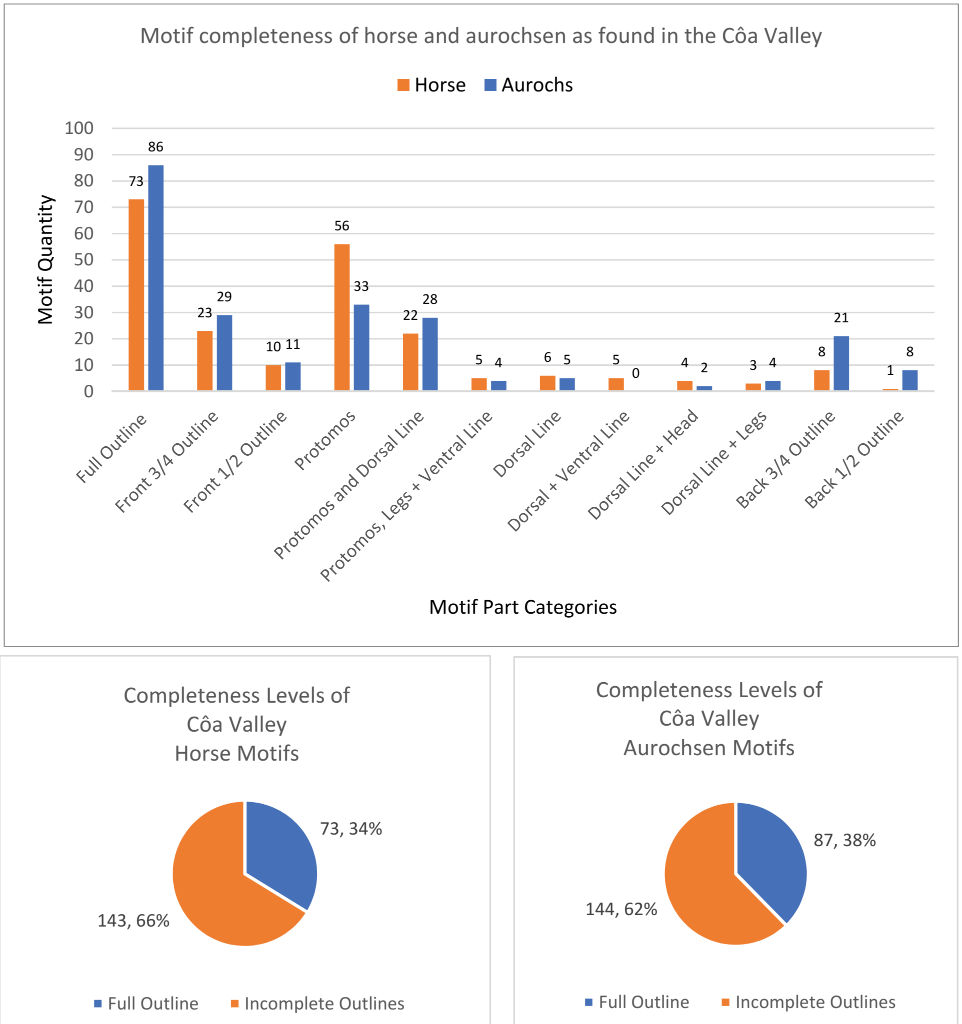

Figure 6. The completeness levels of horse and aurochsen depictions in the Côa region together with their respective overall percentages.

made redundant and if, reductively, the head alone can signal identification, why would artists go to the trouble to display additional features? One conceivable answer would be that the total economizing of time (i.e. expedience) was not important in all cases, and that their representations were not made *purely* for onlookers to swiftly identify their creations but were instead made for a different purpose. Perhaps these depictions were for a more *artistic*, feature-rich purpose and were less cognitively-driven? Perhaps the physical demands of engraving hard stone dictated a compromise between achieving saliency and economy of making?

The hunter = the artist?

The question of authorship has been debated by rock art researchers since the discovery and authentication of prehistoric art. Specialists have not explicitly distinguished between the artist, the hunter, or a possible amalgamation of both. Readers can be forgiven for assuming that the person who created the art will have also been the hunter in return; this assumption is usually made, however implicitly, in Palaeolithic art studies. In fact, our experimental analysis is heavily targeted towards the implication that the artist was in fact the person who would have used their observation abilities to facilitate and improve successful hunting, which is why in turn the art takes its characteristic forms. But what if, in fact, the art was not created by the hunter at all, but by an artist independent of hunting activity, and that the diagnostic information features in *Bubbles only* apply to hunters or artists but not both? Given the fact that being able to hunt successfully was key to the survival of Upper Palaeolithic groups, the abundance of depictions that signal exactly this information – namely those features necessary for successful detection and discrimination of prey – would give rise to **hunters also being involved in the conception of images and, therefore, the art making process.**

Additionally, hunters will have, undoubtedly, been steeped in knowledge of animal behaviour. They would have continuously gained insights into their preys' ethologies; their physical appearances including coats and how they reflect seasonality and health; their behaviours and moods; their posture, movement and manners; their sexual receptiveness and competitiveness. With this rich knowledge in mind, coupled with the hunters' own respective degrees of alertness, power and fear, could it not be argued that hunters wanted to reflect their wealth of knowledge of these idiosyncrasies by way of engraving very detailed depictions of animals, i.e. that they were not just depicting taxa but personalities? This question might provide the clue as to why some more elaborate depictions are found, namely for hunters to educate others about their features. Examples of the sorts of details that could have been used in such teaching might include the moulting shape or 'M-shape' characteristic, frequently found on horse bellies, which indicates a change in seasonal coats. This special feature of Przewalski's horses (in addition to which, moulting often leaves clumps of winter coat – perhaps the 'dots' seen in some Upper Palaeolithic paintings) cannot have gone unnoticed by hunters. Despite the fact that the M-shape does not contribute to a horse's diagnostic information in a major manner, this colour change would qualify as a special feature. Accordingly, in rock art locations at which M-shaped horses do appear, hunters might have wanted to record their sightings of these more undiagnostic, seasonal animal changes, and thus deemed the M-shape worthy of portrayal. Whatever the specifics, all of these scenarios, point to **hunters as facilitators of the art, be it in their hunting/discrimination mode or in their teaching/memory storage, more elaborate feature mode.**

Conclusions

While our study should be regarded as a pilot, it does allow us to generate some falsifiable predictions about the nature of Upper Palaeolithic animal depictions. We should emphasize that we are not trying to be reductive, i.e. ascribing as much as possible of early human visual culture to 'psychology' but that in our attempt to put our understanding of the emergence and early development of 'art' on a more scientific basis we are interested in exactly how our visual psychology stimulates, constrains and forms the specific nature that surviving examples take.

Visual psychological processes explain why animals are depicted in the way they are. We suggest that the *Bubbles* technique is a feasible method for exploring stimuli other than human face recognition. As the *Bubbles* methodology can be used to mimic responses from rock art making, we are optimistic that our study will pave the way for further applications of the technique to more Upper Palaeolithic scenarios (and to other archaeological periods and tasks) with their psychological underpinnings.

We can identify the most diagnostic features on (1) a horse and (2) a bison, that actively aid the identification of these particular species. The classification images we have established reveal particular areas that entail diagnostic taxonomic information, which can be used to distinguish between species. Horses are most commonly identified by their outline, with particular emphasis on the dorsal line and the areas of the head. Bison are distinguishable by their visually salient hump and their protomos extending towards their front legs. The fact that this diagnostic information varies between species indicates that each type is identifiable by their most diagnostic parts and that the *Bubbles* technique succeeds in characterizing these features.

The minimal amount of information needed for detection or discrimination of a specific animal taxon, as revealed by the *Bubbles* method, corresponds to the features most commonly emphasized in rock art. Overall, the features that human perception prioritizes are the same as those that are most commonly observed in rock art depictions. Aspects otherwise uniformly present within all species, such as feet, detailed coat interior lines or eyes, are commonly omitted from rock art. This suggests that rock art creation was cognitively-driven, mimicking the information most necessary for hunters to distinguish prey species. To put this another way, we predict that those parts of an animal's outline that are most important to correct discrimination were under constant cultural selection for elaboration (and change) in art.

As the features most commonly emphasized in rock art resemble the diagnostic information established through *Bubbles*, we can infer that hunters were closely involved in the art-making process. Despite the abundance of diagnostic features within motif parts, which would point to hunters illustrating these creations in line with what is necessary for distinction, a number of rock art examples exhibit far more elaborate depictions. This suggests that another underlying reason for rock art creation was at work, corresponding to the need for elaborate teaching and memorizing of places at which features were seen, that go beyond those of the visual saliency we have discussed. Given this, we infer that individuals who were active hunters would have played a key role in the facilitation or in the guidance of art making. It could be suggested that the aforementioned steppe environment can be linked to the missing depictions of lower limbs and hooves, hidden as they may have been by long grasses and shrubs.

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No potential conflict of interest was reported by the authors.

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