Eyes on the Past: Visual exploration of Upper Palaeolithic cave art

Frederieke Nicola Wullf (202105369@post.au.dk)
Department of Linguistics, Cognitive Science and Semiotics,
Jens Chr. Skous Vej 2, 8000 Aarhus, Denmark

Sara Kjær Kristensen (202105320@post.au.dk)
Department of Linguistics, Cognitive Science and Semiotics,
Jens Chr. Skous Vej 2, 8000 Aarhus, Denmark

Izzy Wisher (izzywisher@cas.au.dk)
Department of Archeology and Heritage Studies, Aarhus University
Moesgård Allé 20, 8270 Højbjerg, Denmark

Kristian Tylén (kristian@cc.au.dk)
Department of Linguistics, Cognitive Science and Semiotics &
The Interacting Minds Centre
Jens Chr. Skous Vej 2, 8000 Aarhus, Denmark

Abstract

The European Upper Palaeolithic is rich in figurative cave art. In particular, prey animals are often depicted in simple schematic outlines. The role and function of these depictions is subject of controversy with competing accounts represented in the literature. Here we apply eye-tracking to investigate participants' distribution of visual attention as a function of three hypothesized pragmatic functions of the cave art: aesthetic appreciation, narratives about animal behavior, and social learning of animal species. Results indicate vast variability in visual exploration patterns across the viewing conditions, with more uniformly distributed attention in the aesthetics condition, more focus on legs and torso in the behavior condition, and more attention to the head regions in the species recognition condition. Findings are discussed in regards to the under- and over-specification of information in the animal paintings as a cue to their possible past function.

Keywords: cave art, eye-tracking, aesthetics, narrative, social learning

Introduction

Art making runs deep in our evolutionary history. *Homo sapiens* engaged in artistic behaviours over 100,000 BP in the form of abstract engravings, with figurative art emerging perhaps as early as over c. 44,000 BP in Indonesia and flourishing during the Upper Palaeolithic (c. 40,000-13,000 BP:(Aubert et al., 2019; Henshilwood et al., 2009). Upper Palaeolithic figurative art is overwhelmingly dominated by prey animals (e.g., bison, horse, deer) that were depicted in highly variable ways, from abstract outlines to intricately detailed, naturalistic depictions. This variation was initially attributed to a unilinear evolution in drawing capabilities, with naturalistic depictions emerging towards the end of the Upper Palaeolithic (Breuil, 1907; Leroi-Gourhan, 1968). Whilst it is now clear that different modes of representing animals coexisted during the same period, and often even within the same cave, there is still significant debate surrounding the artists' intentions and why there was such variation in depicting animal outlines during the Upper Palaeolithic. In recent years, interdisciplinary approaches have demonstrated significant potential in introducing more systematic ways of empirically testing of different hypotheses and interpretations pertaining to Palaeolithic art (Meyering et al., 2020; Tylén et al., 2020; Wisher et al., 2023b). In this paper, we utilise eye-tracking to determine whether visual interactions with figurative art vary under different experimental conditions and if this might, in turn, indicate whether the variation observed in Upper Palaeolithic figurative art reflects different contexts of use.

In the archaeological literature, there are a multitude of interpretations intending to account for the past role of cave art giving rise to the profound variation observed in animal depictions. In the first account, figurative cave art is approached from the perspective of art history and assumed to be driven primarily by aesthetic intentions by the Palaeolithic "artist"; merely "art for art's sake" (Halverson et al., 1987; Moro Abadía & González-Morales, 2006). These interpretations propose that figurative cave art was produced primarily for aesthetic pleasure - an "impulse of leisure" - drawing from the detail and composition present in certain Upper Palaeolithic cave art sites, and analogous comparisons with children's spontaneity when engaging in drawing behaviours (Halverson et al., 1987). Through this perspective, variation in the form and detail of animal depictions thus reflects dimensions such as skill or cultural aesthetic preferences (Moro Abadía & González-Morales, 2006).

Other accounts assume the activity of cave art to be an integral part of broader socio-cultural behaviours related to

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subsistence, that reinforce ethological knowledge about animals. These tend towards two perspectives. The first suggests that animal depictions encode information about specific behaviours. Several authors (Azéma, 2008; Guthrie, 2005) have compared animal behaviours to the positioning of anatomical elements in figurative cave art depictions, arguing that these are intended to capture specific ethological information, such as “alerted” states of hinds or resting behaviours of bison. Further, deeper understanding of Pleistocene animals has reinforced ideas that certain details featured in figurative depictions are not a reflection of cultural stylistic choices, but rather faithfully capture variation in Pleistocene species (e.g., the dotted horses in cave art may reflect a genetic expression of dots in the coats Pleistocene horses: Pruvost et al., 2011). This both suggests that Upper Palaeolithic figurative art inherently reflects the deep ecological knowledge of Upper Palaeolithic hunter-gatherers, but also may have functioned as a tool for which to integrate this knowledge within ontological behaviours, e.g. storytelling.

A third interpretation suggests that cave art is a means through which animal species were socially learned, with partial animal depictions especially facilitating training in the rapid identification of animal forms. The heightened arousal state of cave environments has been perceived as akin to the arousal state triggered during hunting activities, and thus a suitable environment for which to socially learn the fragmented cues of animal forms, i.e., animals partially obscured by vegetation in the landscape (Hodgson, 2008). More generally, other studies have suggested that the cervical-dorsal line of animal depictions, frequently the only anatomical feature retained in partial depictions of animals in Upper Palaeolithic art, may be the most salient for rapidly identifying the species. To this end, Meyering et al. (2020) conducted an experimental study using the “bubbles” technique, that empirically supported this perspective; participants were able to more rapidly identify animals when part of the head and back were visible.

Derived from these interpretations prominent in the archaeological literature, we summarized three hypothesized functions of figurative cave art: i) cave art as objects of aesthetic appreciation; ii) cave art as informing about animal behaviours, either through narrative storytelling and/or as a means of teaching; iii) cave art as playing a role in social learning of rapid species identification. We propose that each context of cave art use would necessitate specific visual information to be encoded within the art. To address this, we experimentally tested which areas of an animal outline receive the most visual attention during conditions that replicate these use contexts. We focused on the art of the Monte Castillo caves (El Castillo, La Pasiega, Las Monedas and Las Chimeneas) in Cantabria, Spain. These cave art sites reflect a breadth of variety in animal forms, that do not necessarily appear to be associated to temporal stylistic changes (e.g., animals may be rendered in different degrees of completeness and detail on the same wall and using the same production technique). Previous research on the Monte Castillo cave art has also demonstrated that the degree of detail incorporated into the animal depictions does not seem to be necessarily related with low lighting conditions of torch- or lamplight, or pareidolia effects, where natural features of the cave wall, such as cracks, may be incorporated to “complete” an animal depiction (Wisher et al. 2023a). Thus, there may be external social and cultural factors, unrelated to the context of making (light, natural features) but pertinent to the use contexts of the art, that may be motivating the degree of completeness of animal depictions. We argue that the different patterns of visual attention in each experimental condition may indicate why certain features of animal forms may be over- or under-represented within figurative Upper Palaeolithic cave art.

Eye-Tracking as a Tool

The same cave art representation can be visually explored in several ways, with attention allocated to different parts depending on the context of the viewing episode. As animal depictions are hypothesized to form part of activities related to aesthetic appreciation, narrative, or species recognition, we hypothesize differences in the exploration and weighting of visual information. Eye-tracking is a method that enables us to record—with high temporal resolution—how spectators allocate their visual attention given different contexts of viewing some stimuli. The method is thus well-suited to investigate which information is sought out when a spectator is approaching a stimulus for its aesthetic, narrative, or informative purpose, and might thus inform general inferences about why and how particular information is under- or over-specified in an animal outline (Dobrez & Dobrez, 2013; Meyering et al., 2020).

This experiment will employ different eye-tracking measures to analyse the distribution of visual attention of individuals looking at cave art. Specifically, we use the proportion of dwell time and first fixation in a specific area of interest (AOI) to investigate which areas of an animal outline the participants fixate upon as a function of different viewing contexts. The experiment thus presents three distinct tasks and investigate differences in gaze patterns between the tasks. In the aesthetic task, participants are instructed to explore the animal outline for their aesthetic appeal and rate it on a scale. In the movement task, participants are instructed to inspect and categorize the behaviour of the depicted animal. Last, in the species recognition task, participants are instructed to discern and categorize the animal species.

More concretely, we hypothesize that when engaged in contexts of aesthetic exploration, participants will distribute their visual attention more evenly across the animal outlines compared to the other viewing tasks, measured as a relatively uniform distribution of visual attention across different AOIs (Hypothesis 1). In contrast, when participants are inspecting animal outlines to determine their depicted behaviour, we predict that they will exhibit a higher degree of visual attention towards the animal's legs, compared to the other viewing tasks (Hypothesis 2). Last, when participants are instructed to indicate the species of animal, we will observe higher degree of visual attention towards the animal's head, compared to the other viewing conditions (Hypothesis 3).

Materials and Methods

Participants

Forty-one participants (22 females, 19 males), mean age 25.4 (SD = 8.6), participated in the experiment. The participants were recruited through Cognition and Behaviour Lab's participant system (SONA). The experiment was approved by the local research ethics committee, and all participants gave informed written consent. Participants were compensated with DKK 100 (~$14).

Stimuli

The stimuli consisted of thirty-five traced outlines of figurative cave paintings depicting animals produced from photographic fieldwork images from the Monte Castillo caves (taken by [anonymized] with permissions granted by the Gobierno de Cantabria). Complete depictions of animals, where all anatomical elements of the animal are present, were favoured and, where possible, the images were taken from a frontal perspective to minimise distortion. The outlines depicted seven bison, three aurochs, ten horses, ten hinds and five ibexes. Since bison and aurochs are closely related, similar in their appearance, and often indistinguishable in Upper Palaeolithic cave art, they were collapsed into a single category: 'bison'. The figurative depictions were traced in black and standardized with respect to the size and orientation, with animals always facing left.

Procedure

Participants were presented with the animals outlines in three different task contexts. The order of tasks was counterbalanced between participants. Across all tasks, the main structure of the experiment was the same: each outline was presented for four seconds. After the first second a sound was played indicating that the participant was able to respond using the index and middle fingers on each hand placed on four keys (three in the Behaviour condition). Participants were instructed to answer as fast as possible. The stimuli pool was pseudo randomized such that each stimulus was shown three times in each task, yielding 315 trials per participants.

In the Aesthetics task, participants were asked to evaluate how aesthetically pleasing the animal outline was on a four-step scale from "not beautiful" to "very beautiful". In the Animal Behaviour task, participants were asked to identify whether the figurative outline represented an animal either moving, standing, or lying down, while in the Species Recognition task, participants were asked to identify to which of four categories (horse, bison, hind, ibex) the outline belonged. All tasks were preceded by a practice round, the purpose of which was to familiarize the participants with the response keys so that they could respond without looking at their hands and keyboard. For the practice round, we used photographic depictions of naturalistic animals (the same four species) and the practice trial proceeded until the participant had learned and automated the key-response mappings.

All tasks were conducted using a standard Windows computer with a 19" monitor. An iMotions' Aurora eye-tracker (iMotions A/S, 2022) recorded participants' gaze patterns with a sample rate of 120 Hz. The stimulus presentation and response recording were controlled using the software PsychoPy 2023.2.3 (Peirce & MacAskill, 2018) for Python version 3.8 (Van Rossum & Drake, 2009).

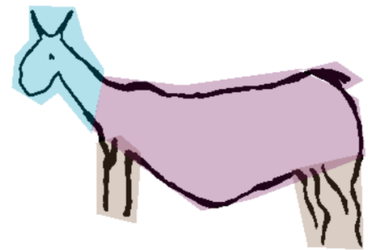

Figure 1: Example of a stimulus outline with the three AOIs; head, torso, and legs, here coloured in turquoise, purple and brown, respectively.

Statistical Modelling

Each stimulus had individually specified areas of interest (AOI) defined for the head, torso, and legs respectively (see figure 1). We tested hypothesized differences in gaze pattern across AOIs and tasks relying on the Bayesian framework with the *brms* package (Bürkner, 2018) for *RStudio* (RStudio Team, 2020). For all models we performed prior predictive and prior-posterior update checks to ensure model performance. We consider two complementary outcome variables: i) *dwell time*, and ii) *first hit*.

Dwell Time was operationalized as the proportion of time spent in an AOI compared to other AOIs standardized to a scale between 0-1. To avoid 0 and 1 inflated results, dwell time was transformed to fit within the bounds of the beta distribution. Dwell time (*DwellT*) was then modelled as a beta distribution in a generalized linear mixed effects model testing the interaction between task and AOI, while including random intercepts for participant (a more complex model including random intercepts for stimulus had difficulties converging). See a pseudo code representation of the model below:

$$DwellT \sim 0 + Task : AOI + (1 \mid ID)$$

First Hit was operationalized the first fixation in an AOI. However, to avoid centrality bias (that the first fixation is always in the middle of the outline at the position of the fixation cross), we used the first fixation following the first saccade. Due to the categorical nature of the first hit variable, we used a mixed effects logistic regression with the interaction between task and AOI as fixed effect, and random intercepts per participant and stimuli:

$$First\ hit \sim 0 + Task : AOI + (1 \mid ID) + (1 \mid Stimulus)$$

Hypotheses are tested relying on *Evidence Ratio* (ER), which is an expression of the posterior probability of the directed hypothesis against the posterior probability of all alternative hypotheses (including the null hypothesis). Since for hypothesis 1, we predicted that the attention would be more uniformly distributed in the aesthetics tasks than the other tasks, in this case we calculated a difference score between estimates for the AOI-task interactions, and tested the hypothesis that differences would be smaller for the aesthetics task. Find data and analysis code on the project OSF here: https://osf.io/mg39n/?view_only=f42834b6a251467bb15e2a68365e5afe

Results

Participants' visual explorations of the animal outlines appeared to differ systematically between the three viewing tasks as indicated by the heat map in figure 2.

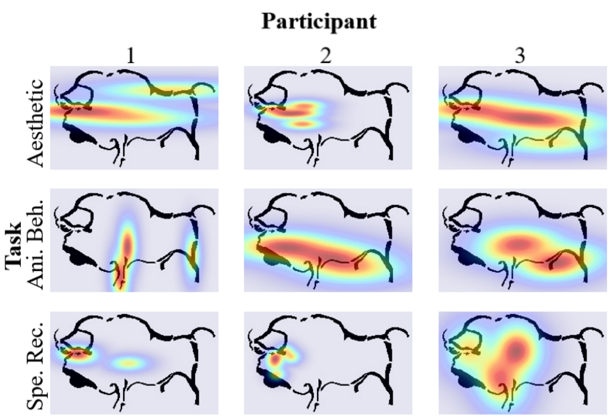

Figure 2: Example of an animal outline and fixation heatmaps from three participants engaged in the tasks. Heatmap colours indicate concentration of fixation rising from blue to red.

Dwell Time

Aesthetic Task We found moderate evidence for a more equal distribution of dwell time between AOIs in the aesthetic task compared to the animal behaviour task, β = -0.04, *95% CIs* = -0.1 0.02, *ER* = 6.61, *credibility* = 0.87, and a strong effect when comparing the aesthetic task to the species recognition task, β = -0.36, *95% CIs* = -0.44 -0.27, *ER* > 1000, *credibility* = 1, supporting hypothesis 1.

Animal Behaviour Task In support for hypothesis 2, we found a credible difference with participants paying more attention to the legs AOI in the movement task compared to the other tasks, β = 6.69, *95% CIs* = 5.36 6.03, *ER* > 1000, *credibility* = 1.

Species Recognition Task Last, we found a credible difference with participants paying more attention to the head AOI in the species recognition task compared to the other tasks supporting hypothesis 3, β = 1.71, *95% CIs* = 1.40 2.04, *ER* < 1000, *credibility* = 1.

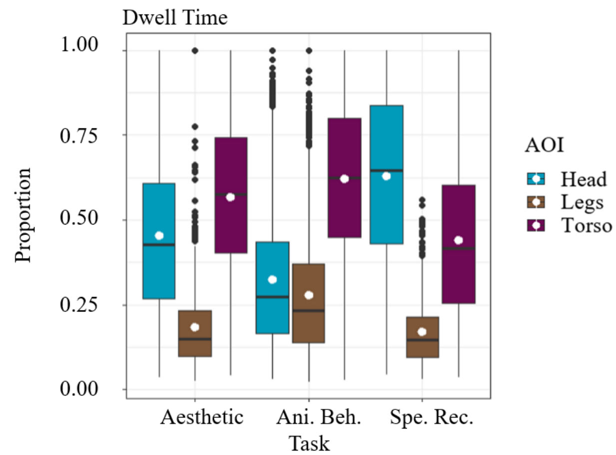

Figure 3: boxplot displaying the proportion of dwell time for each AOI in the three tasks. The black dots being observations and the white dots indicating the mean.

First Hit

Aesthetic Task We found no evidence for the first hit being more equally distributed across AOIs, when comparing the aesthetic and the animal behaviour task, β = 4.16, *95% CIs* = 3.82 4.53, *ER* = 0, *credibility* = 0. However, there was a moderate effect when comparing the aesthetic and species recognition task, β = -0.40, *95% CIs* = -0.92 0.12, *ER* = 8.32, *credibility* = 0.89, leaving partial support for hypothesis 1.

Animal Behaviour Task When comparing the legs AOI in the movement task to the other tasks, a credible positive effect was found supporting hypothesis 2, β = 2.89, *95% CIs* = 2.59 3.17, *ER* < 1000, *credibility* = 1.

Species Recognition Task In support of hypothesis 3, the proportion of first hits on the head AOI was higher in the species recognition task than in the other tasks, β = 2.13, *95% CIs* = 1.59 2.59, *ER* < 1000, *credibility* = 1.

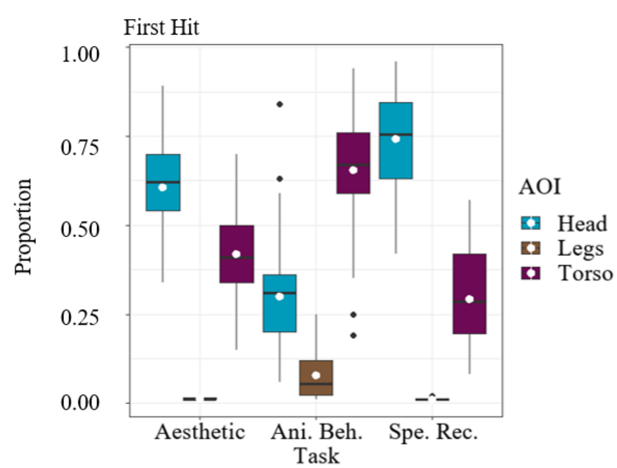

Figure 4: boxplot displaying distribution of first hits for each AOI in the tasks. The black and white dots being respectively observations and the mean.

Discussion

Overall, we found substantial variation in participants' visual exploration of animal outlines depending on the context of viewing. As we vary the pragmatic function of the outlines motivated in hypothesized original intentions behind figurative cave art, we observe that participants systematically seek out different kinds of information from the outlines.

With respect to hypothesis 1, we predicted that when participants explored the animal outlines for their aesthetic qualities, they would tend to distribute attention more evenly across the animal outlines compared to the other viewing contexts (Massaro et al., 2012). Eye-tracking studies have suggested that when presented with an artwork, spectators will start by doing a first scan to gain an overview, after which they "visually scrutinize" the artwork, by returning to interesting or salient pictorial features, from which an aesthetic assessment can be generated (Locher et al., 2008).

We observe a more equal distribution of attention in the aesthetics task compared to the species recognition task with respect to both dwell time and first hit. When comparing the aesthetics task to the behaviour task, we observe a (weak) effect for *dwell time*, while there appear to be no difference for the *first hit*, lending partial support for hypothesis 1. However, as the prediction for aesthetic appreciation concerns a broader visual exploration of the animal outlines, in correspondence, for instance, with the observations of Locher et al. (2008), dwell time could be considered the more appropriate measure for this hypothesis. As evident from figure 4, the first gaze is usually attracted to the head region, which is the more salient and information dense part of the outline (Cheyne et al., 2009), and almost never to the legs, which give rise to the less uniform distribution of first hits.

Motivated by other theories about the role of cave art as accompanying narratives about animal behaviour, hypothesis 2 predicted that participants would direct their attention to the leg region of the outlines to scrutinize aspects of animal movements. Indeed, we observe that when the behaviour of outlined animals is actualized, participants pay more attention to the leg regions (*dwell time*) and will more often gaze immediately to the legs (*first hit*) compared to the other viewing contexts supporting our predictions. However, as evident from figure 3 and 4, despite the contrastive difference to the other tasks, participants are also in the behaviour task looking more at the other AOIs (head and torso) than at the legs. There are several potential reasons for this. On the one hand, animal movement is not only a matter of leg position. Sometimes other cues involve the posture of the neck and head, a mane blowing in the wind, a raised tail, or the curving of the animals back indicating movement (with fixations more likely to fall in the torso and head AOIs, Azéma, 2008). Conversely, as stated earlier, many drawings from the Upper Palaeolithic period are not complete outlines but will often have parts missing or hidden behind crags or corners in the rocks (Hodgson, 2013; Meyering et al., 2020). In particular, there is a tendency to underspecify the leg region in several of the stimulus outlines making it unlikely or practically impossible to record fixations in this region.

Last, we predicted that when tasked with identifying the animal species, participants would pay more attention to the head region of the depicted animal. Indeed, we find that both with respect to *dwell time* (i.e., proportion of fixations) and *first gaze*, participants direct their attention to the head region to seek out information that can support them in deciding the species. These observations corroborate findings by Meyering et al. (2020), that using different methods, also found that the head and its further connections, such as the hump on the back or the headgear (e.g., antlers or horns) appeared to be the most salient features for species recognition.

Implications for Cave Art

Making assumptions about the past predispositions of our Palaeolithic ancestors is a difficult discipline. There are huge gabs to fill between the sparse archaeological remains and the ambition of researchers to address aspects of past behaviour and cognition. This often leads to situations where there are several competing interpretations of the same archaeological findings. This is indeed the situation with figurative cave art, which historically has been characterized by numerous alternatives and sometimes conflicting accounts. While we probably cannot hope to fully resolve such controversies, one way forward is to acquire relevant additional empirical data in the form of supporting contextual information that can weight for or against individual interpretations (Hodgson & Pettitt, 2018). Our study can be seen as a small brick in such a larger puzzle, bringing in cognitive/perceptual data to complement archaeological and anthropological investigations.

The analysis of participants' gaze patterns highlights the dynamic interplay between properties of the stimulus, task demands constituted by the context of visual exploration, and participants' cognitive strategies. By recording eye-gaze behaviours in response to different pragmatic functions of figurative cave art suggested in the literature, we can obtain data to test specific hypotheses. Our observations can support inferences about what parts of animal outlines will be perceived as important and thus relatively more or less specified as a function of their role in past Palaeolithic activities and might thus—in combination with other forms of evidence—support interpretations of the original intentions of the cave artists. Our perceptual experiments thus complement structural-morphometric analyses of cave art depictions attempting to map local information density and distortions possibly utilized by cave artists to support their role in particular activities (Cheyne et al., 2009).

In the current study, we relied on a particular collection of figurative cave drawings from the Monte Castillo caves in Cantabria, Spain. Direct AMS radiocarbon and indirect U-Th dating of overlying calcite of some depictions within these caves demonstrate there is a deep chronology to the art, with the earliest non-figurative motifs produced over 40,000BP and the youngest figurative depictions produced c. 15,000 BP (Pike et al., 2012; Valladas et al., 2001), spanning the entirety of the Upper Palaeolithic. This diachronic dimension opens another set of intriguing questions related to the evolution of human symbolic behaviour. The literature on cave art has often been concerned with discussions of *the* function of cave art, assuming a particular intention or function (e.g., 'hunting magic', ritual, or artistic expression) to account for the profoundly varied activities straddling tens-of-thousands of years (Hodgson & Pettitt, 2018). A more nuanced approach would be to investigate how functions might have changed and/or diversified over time analogous to how other more instrumental technologies and practices have been observed to complexify during the same period (Ambrose, 2001).

Further research

This study demonstrates the vast potential of utilising experimental approaches to address contrasting interpretations and hypotheses about ephemeral past behaviours (Tylén et al., 2024). While we present important implications of our study for understanding how the context in which animal depictions in cave art were used may have affected the under- or over-representation of specific visual information, there are certain questions that remain to be addressed in future research.

Notably, the context in which the depictions are situated undoubtedly constrained and affected their interpretation and use. Cave art appears to have been produced with sensitivity to the topography of cave walls (i.e., natural undulations and cracks, Wisher et al., 2023a), and deliberately placed in either constrained or open spaces within the cave. When stimuli are removed from this environment and presented in the impoverished experimental format as black and white 2D outlines, there is a risk that the depictions become distorted and visual information is lost. Although we were primarily concerned with evaluating whether different conditions of use can result in different patterns in the visual interrogation of stimuli, further research may pay greater sensitivity to the context in which stimuli were situated, and how this affects the way depictions are visually engaged. Recent research using virtual reality (VR) cave environments have demonstrated the potential of integrating eye tracking within a more ecologically valid environment (Wisher et al., 2023b); this kind of approach may be beneficial for further research.

Additionally, experimental studies of the sort presented in this study rest on the assumption that data obtained from contemporary participants can potentially inform insights of the workings of past Palaeolithic minds. While Upper Palaeolithic people were anatomically and behaviourally "modern" *Homo sapiens*, and thus likely had similar cognitive capabilities as contemporary humans (Stibbard-Hawkes, Accepted), this does not address the effects of using W.E.I.R.D. participants to assume universals about past and present human cognition (Henrich et al., 2010). This is particularly pertinent when testing the effects of different conditions that are implicitly influenced by cultural milieu, such as the aesthetics condition. We thus encourage further research that uses a broader cross-cultural participant sample. This may facilitate addressing nuanced questions pertaining to how, for example, stimuli in the species recognition condition are interrogated in different ways by experienced hunters in small-scale hunter-gatherer societies that have expertise in distinguishing animals in the landscape.

While this experiment focuses on how cave art is perceived contingent on different viewing contexts, the study's overarching purpose is to support inferences about the original intentions behind the creation of figurative cave art. Figurative cave paintings significantly vary in drawing style and the amount of detail provided for different body parts of the depicted animals. Our results indicate that depictions where most detail is present in the head region, could serve a context where species recognition plays a crucial role, supporting previous experimental observations for other kinds of Palaeolithic figurative art (Meyering et al. 2020). Our results also indicate that animal depictions for which more detail is provided specifying animal movement (e.g., the leg region) might have served other purposes, perhaps involving narrative content. Lastly, we suggest that when animal outlines are overall rich in detail, it could reflect an aesthetic intention in the cave artist. However, these experimental observations primarily concern behaviours of the "viewer" and thus the context in which these depictions may have been engaged with, rather than produced. An important next phase in our study is thus to experimentally investigate how the distribution of visual information present in the depictions themselves varies when "artist" participants create animal drawings in different functional contexts. Adding together such systematic experimental efforts can qualify our inferences and support theoretical efforts in understanding the intentions behind Upper Palaeolithic cave art.

Conclusion

Our study demonstrates that different functional contexts of Upper Palaeolithic figurative cave art affect the way the depictions are visually explored. We suggest that this may provide one explanation for why certain visual information in animal depictions may be over- or under-represented, with exaggerated or missing features of depictions potentially indicating different contexts of use. These kinds of empirical approaches to understand enigmatic behaviour from the deep past have significant potential for enriching archaeological interpretations. Experimental approaches that utilise stimuli derived from the archaeological record can facilitate the systematic assessment of competing interpretations and generate new data that can help address questions pertaining to the evolutionary processes that influenced our cognition today (Tylén et al., 2024).

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