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Materialities, Space, Mind: Archaeology of Visual Cognition

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For Juan Vicent

Abstract

A perceptual study of different styles of prehistoric Galician ceramics (from 6000 to 2000 BP) conducted by eye-tracking, underpins the material engagement of mind by showing that the visual world fosters the entanglement between doing, seeing, and designing through history. This text examines how materialisations of human practices relate to cognition and to socio-cultural contexts. By combining evidence on the relationship between material culture and perceptual reactions, our text aims to understand the entanglement between the mind, objects and the world. We apply measurable and numeric techniques, providing an archaeometric approach to cognitive topics by combining neurosciences with interpretive and reflective research. This research provides new insights into the material culture, contributes to the understanding of the relationship between mind and the material world, and accounts for the transitive engagement between the way of thinking, seeing and making things. Thus, the text contributes to an understanding of the material forces driving perception and thought.

Topics[1]

In recent years two ideas have become increasingly popular in the archaeological debate. One is the agency of objects. The other concerns what we might call the emergence of the res extensa in social and cultural analyses. Archaeology has strongly contributed to the recognition of the importance of the body, space and materiality in social action. Indeed, the embodiment of ideas has made it possible to move away from the interpretative excess that post-processualism reached, renewing a genuine interest in things. Upon closer inspection, these ideas have been around for quite a while, whether explicit in some philosophical elaborations or implicit in different archaeological theories. Recently, the so-called 'new materialisms' have sought to unify both matters by shifting them to the realm of ontology. Here, the capacity to act or the impact of materiality on the subject is attributed to the 'being' of things (Olsen 2011; Olsen et al. 2012; Witmore 2014). To date, however, this approach has failed to offer any demonstrable evidence that goes beyond the speculative nature of its approaches. Materiality certainly produces effects that are related to broader socio-cultural processes, but highlighting this correlation is not enough, just as it is not

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[1] The present paper was first published in Spanish: Millán-Pascual et al. 2021.

enough to obscure the issue further with foggy ideas. Recent advances in neuroscience and visual cognition studies of materiality are applied in this article, bringing together the agency of things and processes of embodiment in a novel approach. We believe that this approach opens up possibilities for the investigation of these processes' cognitive dimension and incidentally illuminates essential aspects of those ideas. Moreover, we offer an empirical method capable of mediating between problems that, from this point of view, have not been thought of together: visual perception, cognition and materiality.

Embodiment has been formulated in the hypothesis that the body and its perceptual faculties perform much of the cognitive processes, going even so far to "replace the need for complex mental representations" (Wilson/Golonka 2013, 1). Other approaches to this phenomenon have produced similar claims, which were demonstrated in different settings (Lakoff/Johnson 1980; Malafouris 2013). These studies suggest that cognitive processing does not only take place at the prompting of the brain, but in relation to the material structure of perceptual stimuli (Meteyard et al. 2012). This implies that the long-standing dualism between mind and world does not refer to two separate ontological entities, deciding *a posteriori* which one reduces the other. On the contrary, such a separation is a strictly methodological distinction applied to an integrated reality, in which mind and world operate together and nourish one another[2]. Cognition occurs both inside and outside the mind. There is a biological embodiment in which the brain reacts to electromagnetic waves in the world, as documented by certain synaesthetic processes (Moos et al. 2013) or by well-known experiments such as Takete-Maluma (Köhler 1929) or phonosymbolism (Hinton et al. 1994; Tsur 2006). In addition, there is also a higher-level embodiment that would be the evolutionary result of an intimate entanglement between mind and world that has been proven and is provable in many fields[3]; Classical cognitive research – i. e. the oeuvre of Henry Bergson (2020), as well as different philosophical traditions (Merleau-Ponty 1945; Guattari 1990; Sohn-Rethel 2017), have long proposed this connection. However, the push for new approaches capable of theoretically elaborating the most recent developments in neuroscience has definitively opened up the possibility of studying this field in line with the interests of the human and social sciences (Solms/Turnbull 2002; Malabou 2008; 2012; Metzinger 2009; Brassier 2011; Malabou/Johnston 2013). In the cognitive sciences, theories of the social brain (Dunbar 2009), the extended mind (Clark/Chalmers 1998; Clark 2011), the enactive mind (Gallagher/Zahavi 2013) or even the distributed mind (Hutchins 1995; Dunbar et al. 2010) have followed one another. At the same time, in the theory of material entanglement of mind (Malafouris 2013) the increasingly established idea was expressed that material culture, not just the concrete tools but the whole system of objects that humans produce, would be an active device in shaping a close link not only with the world (Alberti et al. 2011), but also with reason (Malafouris 2010), and between both of them. We continue this line of reasoning, contributing solid data and hypotheses thanks to the application of a new methodology that we have recently presented (Criado-Boado et al. 2019).

Simultaneously, there are studies showing that technology is an important factor in shaping the human mind and that *the actionability of objects* has specific effects[4]. These works reinforce the impression that cognitive processes are highly dependent on materiality (Ingold 2007) and that there is therefore a web of humans, things and world (as postulated for example by Hodder's entanglement 2012) that connect culture, biology and matter. However, to this day, the processes that would explain this connection are barely understood. Little attention has been paid to materiality by neuroscientific and cognitive science studies, even if advances have been made. Nonetheless, chronological sequences that would span a period shorter

[2] Clark/Chalmers 1998, 2011. – The harmful effects of a dualism based on the recognition of two integral and fully independent entities are well known, but this rightful critique should not lead us to reject the possibilities of a methodological distinction (in this case between mind and world) that has nothing to do with the above. As the philosopher Ray Brassier (2011, 7) points out: "A dualism is a distinction that fails to explain the connection between the term it distinguishes. Philosophy discriminates, it distinguishes and separates, but always with a view to ultimate integration. In this regard, philosophy discriminates precisely in order to avoid dualism. The animus towards dualism should not excuse insensitivity towards distinction."

[3] Clark/Chalmers 1998; Smail 2008. – In Jablonka/Lamb 2005, a view of evolution is developed that goes beyond the genetic perspective.

[4] Heidegger 1994b; Haraway 1995; Dobres/Robb 2000; Latour 2005; Lemonnier 2012; Lange-Berndt 2015; Robinson/Pallasmaa 2015; Stiegler 1998.

than the totality of human evolution have been disregarded entirely. Moreover, as noted above in the case of the new materialisms, studies carried out in cognitive archaeology and the humanities have a fundamentally speculative bias. As such, they do not provide the basis for methodologies that allow us to clearly validate hypotheses. Therefore, it is still true that in order to examine the mind-world relationship a tracer or proxy is required, as Renfrew, Frith and Malafouris (2008) advanced, allowing us to document how things shape reason. If such a tracer could be found, it might resolve Colin Renfrew's sapient paradox. He referred to the unequivocal, but surprising, fact that the most novel behavioural aspects of the sapiens genus could be defined relatively late (30,000–40,000 years ago), while the biological basis of the human species was established more than 200,000 years ago[5].

Based on Criado-Boado et al. 2019, in this work it is proposed that the *visual behaviour*, relating gaze to visual cognition through eye gestures, is a good proxy that allows for solid hypotheses and rigorous data. Moreover, a cross-sectional approach can be applied if we analyse the visual response to objects from widely differing societies and periods. This way the cognitive imprint objects from different contexts and historical moments produce can be studied, and whether this changes over time and space.

One of the authors has previously published the article "*Megalitos, espacio, pensamiento*" – "Megaliths, space, thought" (Criado-Boado 1989), which proposed a novel interpretative model of monumental architecture and its origins. This model emphasized megalithism as a defined materialisation of the concept of space and the emergence of this strategy of materialisation as the expression of a transformation of the thought process. More specifically, it proposed the transition from Claude Lévi-Strauss's "savage mind" to a rationality inaugurating the "domestication of the world". This gave way to a branch of landscape archaeology which contributed to an archaeology of thought and of the concept of space. Since then, different studies have shown how each specific cultural background's conception of space-time gave rise to different forms of architecture, landscape and even material culture[6]. Nevertheless, none could provide an explanation. Many years later and from a different perspective, this text digs deeper into this line of research. In this paper, a new answer to the question of how materiality produces the relationship between mind, world and space is presented. As a matter of fact, the main topic is not solely visibility, different ways of looking, visual perception or even visual cognition. All the themes discussed here are brought together in *the cognitive relation between social system and materiality.*

Scope

This study elaborates on recently discussed research (Criado-Boado et al. 2019). In said research, several items of prehistoric pottery, pertaining to different styles, were subjected to eye-tracking analysis. Here, we will focus on the theoretical, interpretative and archaeological implications of these results. We consider this to be convenient due to the highly generic nature of the journal where this research was first published, catering to a broad scientific audience and not specifically archaeologists. The original text might not only be relatively obscure to the archaeological public (especially if lacking basic knowledge regarding the mechanisms of visual cognition), but it also did not allow us to expand on the consequences of this research and its theoretical implications for archaeology.

Since Criado-Boado et al. 2019 details the methodology and empirical data of our baseline research, we could avoid these topics altogether. Nevertheless, we think it preferable to briefly present the following, highly theoretical, discussion.

[5] Renfrew has repeatedly returned to this argument since 1996. The most complete statement of the sapiens paradox that follows is taken from Renfrew, Frith and Malafouris (2008, 1935–1936): "If the biological basis of our species has been established perhaps for as much as 200,000 years, then why have the novel behavioural aspects of our 'sapient' status taken so long to emerge? One interesting observation that Archaeology allows us to make, and which also poses a great challenge to the neuroscientist, is that many of the crucial and enduring aspects of the human condition (symbols, values, religion, literacy, etc.) appear relatively recently in the archaeological record and can certainly be seen as the emergent products of various cultural developmental trajectories, rather than innate biological capacities. Could it be then that brain anatomy and the biological endowment of our species Homo sapiens as this emerged between 200,000 and 100,000 years ago is only part of the story? Moreover, would it be more productive, especially from a long-term perspective, to explore the assumption that human intelligence 'spreads out' across the body-world boundary, thus extending beyond skin and skull into culture and the material world?" We are aware of recent research that points to a more complex scheme for the development of symbolic capacities in Homo sapiens, but we believe that these new findings do not invalidate the general premise of the problem presented by Renfrew.

[6] Criado-Boado/Villoch 1998; Prieto-Martínez et al. 2003; Gianotti et al. 2011; Troncoso et al. 2011; Santos-Estévez 2012; Criado-Boado 2014; Espinosa-Espinosa/González-García 2017; González-García et al. 2019; Troncoso 2019; Troncoso et al. 2019.

In the mentioned article, we set out to examine *two different hypotheses*. The first would be that *the material configuration of an object* (i. e., of the material style it represents) *imposes a way of looking that produces perceptual reactions beyond the expected*. This is because it conditions not only where ones gaze is directed or lingers in the visual exploration, but also how even individual observers do so in a homogeneous way. This implies that the representation of the vessel is not static to the observer's mind, but rather a dynamic model that conditions their pattern of visual perception. In other words, this implies that the object is actively included by the perceptual system, thus showing that perception is inseparable from materiality and configuration. From a theoretical and philosophical point of view, this hypothesis addresses a significant problem that has occupied an important share of theories of consciousness and representation. Moving on from the historical debate on representation implies to move beyond the historical understanding of representation as either a material form or as a mental image. The present work implies the overcoming of this duality. For a better understanding of our argument, a small preview of what will follow: the structure of the object imposes a way of looking that not only marks the places that our gaze frequents most (which is what is mainly studied in gaze and eye-tracking analyses), but also predetermines how we do it. How we look at the object, in what order and with which sequence of visual gestures.

The second hypothesis goes a little further as it proposes that over time there has been a *gradual transition from the predominance of a horizontal gaze to a vertical gaze*, following some archaeological hypotheses that we have put forward in other works (Prieto Martínez et al. 2003; Bradley 2012; Criado-Boado 2014). This transition would correlate with other characteristics of each type of society the material styles belong to, particularly with social complexity. This hypothesis, in turn, points to a broader difficulty in research, as it suggests that visual response is analogous to the spatial articulation of each material style. Moreover, it implies that both follow a pattern of change over time and across different types of societies, which is adapted to or imbricated with social evolution. In other words, the extended version of the second hypothesis is that *ways of looking, doing (style) and living (society) are inextricably related* to each other.

In order to fully understand the implications of these hypotheses and the possibility of studying them using eye-tracking techniques, some *basic notions of visual perception* are required. Our eyes make continuous fixations and saccades through sudden movements, moving our gaze from one point to another. We make an average of four saccades per second, but we are not aware of this because of the phenomenon called 'perceptual continuity': our eyes move endlessly, but we do not see our eyes move or tremble at the world. We tend to think that we direct our gaze, when in fact our eyes are making multiple movements. These are largely unintentional, as we show in this study. We fix our attention on a target, which is what is sharply represented to us in our images, but the eye is occupied otherwise. Through constant saccadic movements, our visual intelligence does two important things: it selects the points to focus on next, and it builds a statistical model of the world in our mind. This is precisely why pupillary movements are so informative: they give us access to visual behaviour that is not intentional, but is very revealing of what the visual part of our brain is doing, and thus of our brain's relationship to the world as mediated by sight. Pupillary movements can be recorded with special equipment called an eye-tracker (Fig. 1). In our case we used an Eyelink II (SR Research Ltd., Osgoode, Ontario, Canada) which independently records the movements of each eye at a frequency of 500 Hz by means of two small video cameras. In this type of experiment, the subject is positioned in front of a screen on which the images to be studied are presented (Fig. 2).

Fig. 1. Photograph of the eye-tracking equipment (Photo: F. Criado-Boado).

Adjusting of headset | Signal calibration | Presentation of images | Tracking of eye movements | Registration

Fig. 2. Analysis process showing a participant and the eye-tracking operator during one of the experiments (Photos: F. Criado-Boado).

To test our hypotheses we designed an *experimental process* in which 15 objects were studied (Fig. 3). These ceramic vessels are characteristic of four material styles of five distinctive chrono-cultural moments over a timespan of 4,000 years in a geographical area (distribution in Criado-Boado et al. 2019, supplementary fig. ED7). Different and increasing degrees of complexity and social hierarchy are represented in the chosen ensemble. The ceramics elected for this experimental process are all from prehistoric Galicia (NW Iberian Peninsula), but they correspond to broader material styles and broadly share formal traits with the ceramic evolution of Western Europe (Gibson 2002). They include examples of symbolic pottery from the Late Neolithic-Chalcolithic (Style 2 of this study), Bell Beaker pottery (Style 3), and other styles that show clear parallels with pottery from other territories. Style 1 shows clear similarities with the Middle Neolithic ceramics of Western Europe, and Styles 4 and 5 are in fact chronological variants of the Iron Age ceramic styles.

The experimental process was made up of seven different and successive experiments. In Criado-Boado et al. 2019 and in the current paper, we focus on the empirical results of the three most significant ones. In total these involved 131 subjects of matching age and gender. In experiment 1 (Exp1, laboratory code EXP_14061) we showed photographs of five vessels (Fig. 4), reproductions that were created for this purpose (Criado-Boado et al. 2019, Suppl. SI 1–2), through a technological process that allowed us to obtain objects containing the same formal and visual characteristics as the originals. The participants in this experiment comprised four different sample groups. Three groups consisted of 'experts' of different levels: group 1 (G1) was made up of 13 people who were familiar with the materials and methodology, the working hypotheses and the main objectives of the experiment. It was therefore foreseeable that their visual behaviour would be predetermined, either confirming the predictions or trying to avoid doing so

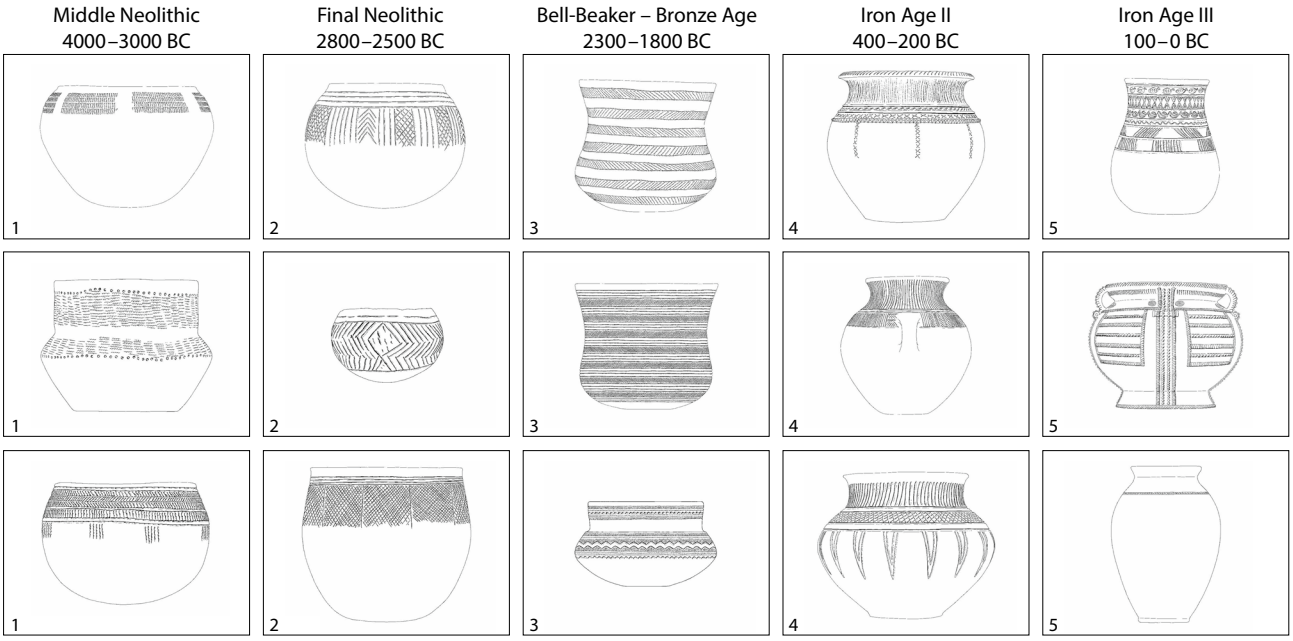

Fig. 3. Analysed ceramic objects, indicating their chronological and stylistic framework (after Criado Boado et al. 2019, supplementary fig. ED1).

in an attempt not to show any bias or feel conditioned. G2 included twelve professionals of Galician archaeology, familiar with the material but not the experiment. The last two groups were not familiarized with specifics regarding the experiment either. G3 grouped eleven ceramists, people who work with ceramics either as craftsmen or artists. In this case it was assumed that their profession and familiarity with the manufacture of the material would affect their visual behaviour. G4 comprised 25 people from the general public, who were therefore non-experts and who had very different levels of education and came from both urban and rural backgrounds.

Fig. 4. Photographs analysed in experiment 1 (Exp1, laboratory code EXP_14061) (after Criado-Boado et al. 2019, supplementary fig. ED8).

Experiment 2 (Exp2, laboratory code EXP_14091) was based on 40 drawings, 15 of which portraying original ceramics (Fig. 3, five of them from Fig. 4), next to five different groups of variations of these vessels (Fig. 5). The aim was to fake visual biases, to artificially force visual reactions by provoking surprise and in this way verify the initial results. 36 subjects took part, 25 of whom had participated in Exp1. Finally, experiment 3 (Exp3, laboratory code EXP_15011) was based on 54 photographs and drawings of different types, among which the vessels of Exp1 were introduced together with variations of these and other images that would allow the working hypotheses to be specified (Fig. 6). Experiments 2 and 3 were carried out after the preliminary analysis of the results of Exp1 and were specifically designed to test or falsify the outcomes. Thus, for example, if we had seen that a decorative style was usually viewed horizontally, in Exp2 we would turn the decoration or the vessel upside down to see if the visual response would be altered congruently.

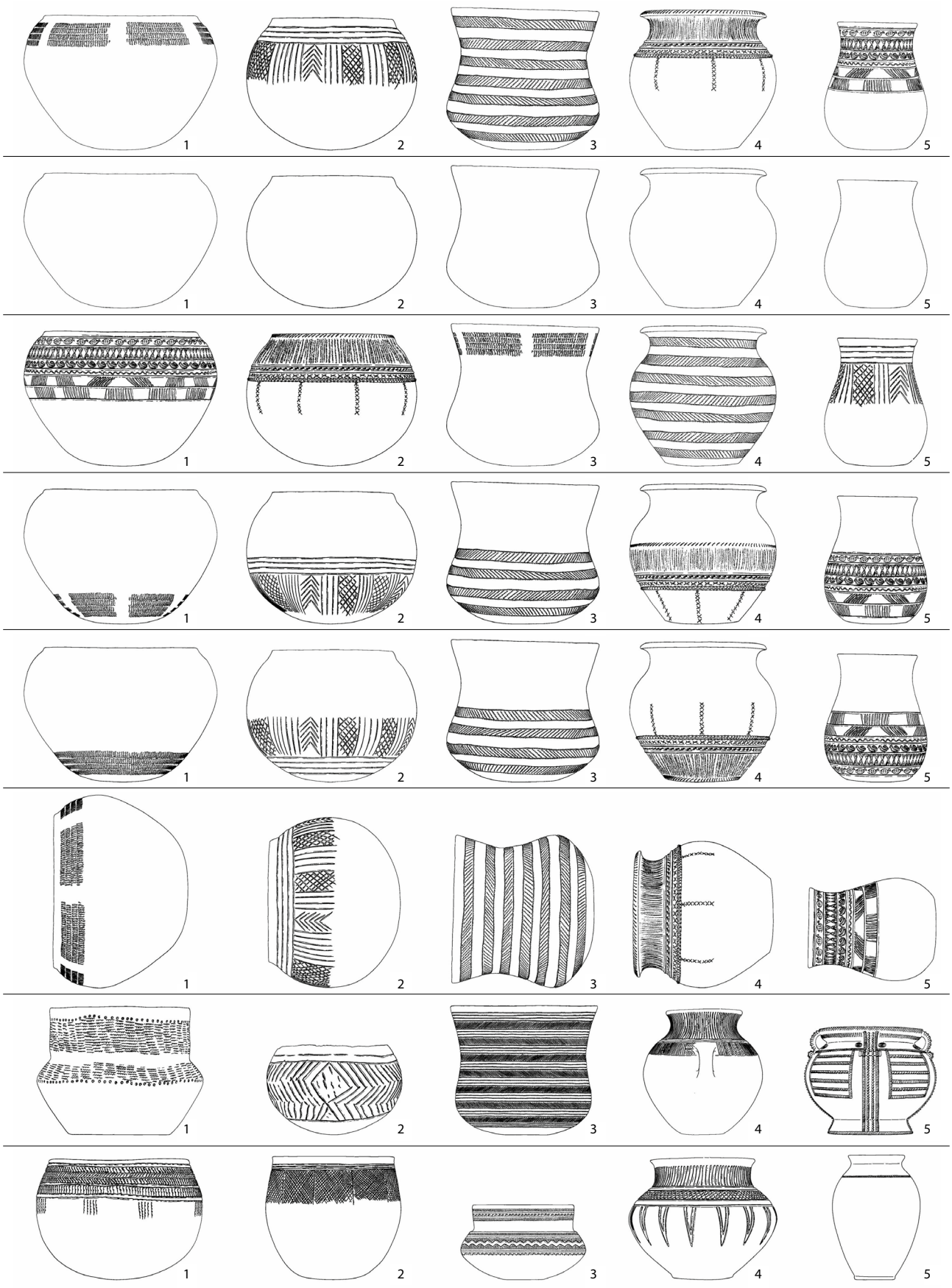

Fig. 5. Drawings analysed in experiment 2 (Exp2, laboratory code EXP_14091) (after Criado-Boado et al. 2019, supplementary fig. ED9).

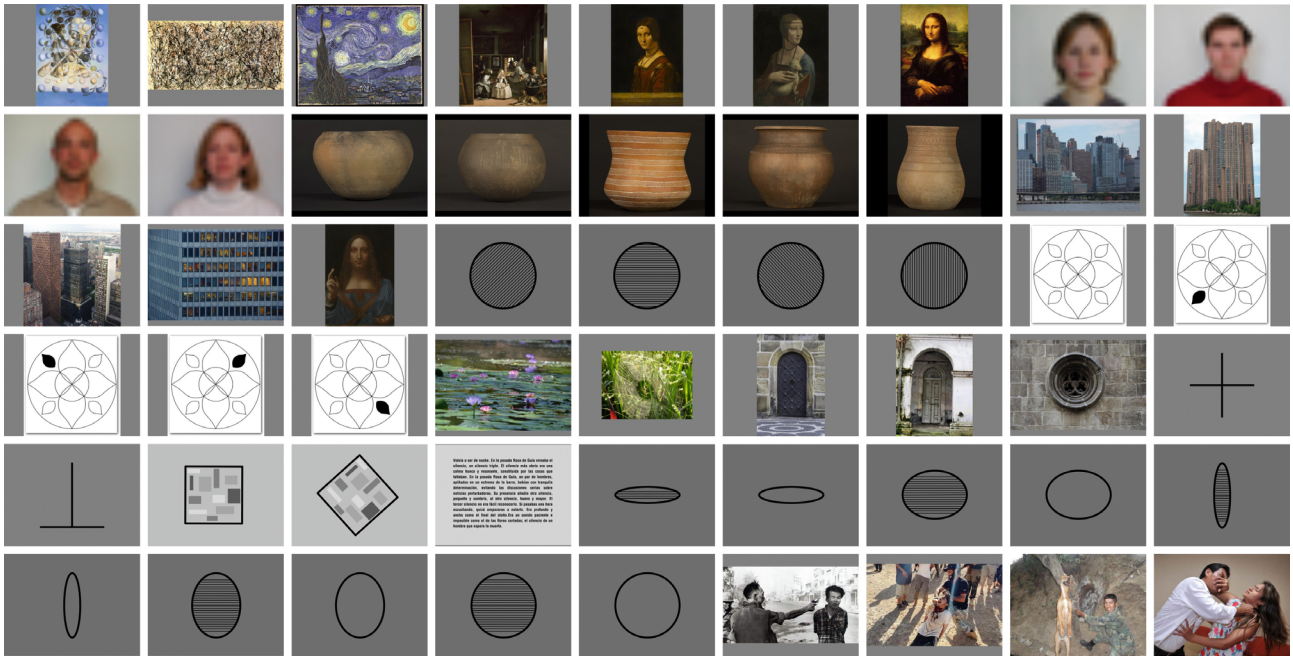

Fig. 6. List of images analysed in experiment 3 (Exp3, laboratory code EXP_15011). From left to right and top to bottom: 1 Galatea of the spheres, Salvador Dalí (1952); 2 Number 31, Jackson Pollock (1950); 3 Starry night, Vincent van Gogh (1889); 4 Las Meninas, Diego Velázquez (1656); 5 La belle ferronière, Leonardo da Vinci (1490–95); 6 Lady with an ermine, Leonardo da Vinci (1490); 7 Mona Lisa; 8–11 Busts of different kinds of people; 12–16 Ceramic objects 1 to 5 from Figure 4; 17–20 architectures with decorative and structural elements from different points of view; 21 Salvator Mundi, Leonardo da Vinci (1500); 22–30 geometrical figures; 31–32: nature; 33–35 historical architectural elements; 36–50 variations of geometrical figures and a text; 51–54 photographs of social violence: 51 man holding a gun to another man´s head; 52 recruit killing a young man by cutting his throat; 53 man in a camouflage suit smiles while stretching a rope that hangs a dog; 54 man attacks a woman pressing her neck, while she tries to push him away (after Criado-Boado et al. 2019, Supplementary fig. ED10).

Results

For the analysis of the empirical results, two parameters were defined. These parameters allowed us to process the visual response to the experiments: the AR and the Vi. The Aspect Ratio (AR) establishes the horizontal-vertical ratio of each vessel. The Vertical index (Vi) or verticality index reflects the ratio between saccades of predominantly horizontal and vertical direction.

Figure 7 presents the most important results reported in Criado-Boado et al. 2019. It shows that, while the AR of the ceramics follows an ascending line, the decoration imposes an ocular response. The Vi reflects that in this forced response, in some cases horizontality prevails and in others verticality. This figure also records the value of salience (different visual features that contribute to attentive selection of a stimulus – colour, orientation, movement etc.; Niubur 2007) of each vessel, and shows how each ceramic style's load of visual information acts as a predictor of visual behaviour.

Figure 8 depicts the preference for horizontal or vertical scanning for each vessel; it includes a graph representing the percentage of saccades in different directions and a sequence of photographs showing the predominant place and direction of gaze over fixed time intervals for all subjects. This information complements the information on Vi in Figure 7 by showing the interrelationship between saccade angles and the topological arrangement of fixation density. Here it becomes clear that the visual content is centred on the decorated parts of each vessel and that, depending on the configuration and internal articulation of the decorative pattern, the visual behaviour differs.

The data show that there are no discernable differences between women and men (Fig. 9) or between age groups, and that the behaviour of the different sample groups is the same (Criado-Boado et al. 2019, supplementary fig. ED13). This might seem surprising at first, as it was expected that the greater familiarity with the artefacts of archaeologists and ceramicists, as opposed to the unfamiliarity of the general public, would generate some kind of bias or clear difference. Nonetheless, not even with G1, the group of people who had a greater degree of knowledge about the experiments, did this happen.

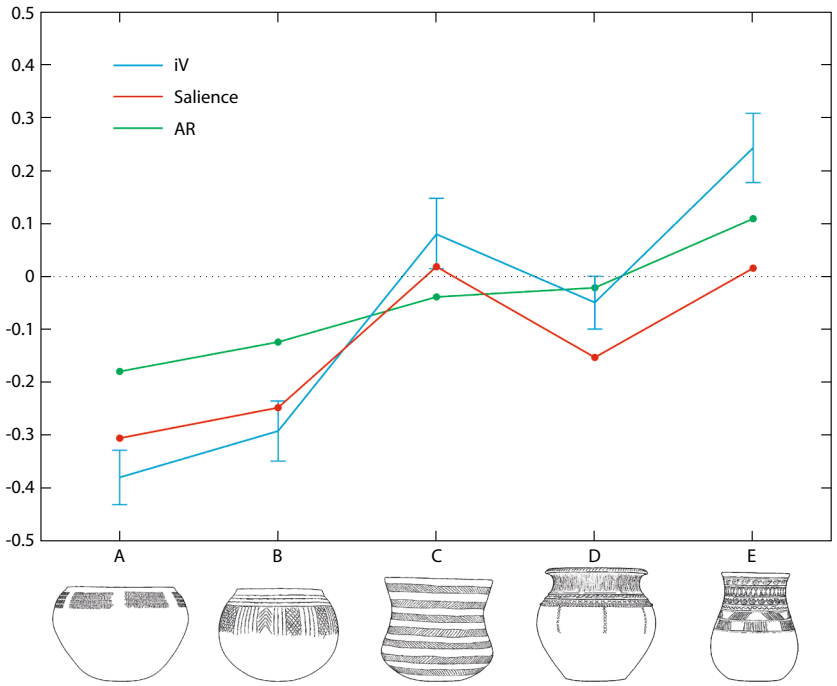

Fig. 7. Vi (Vertical index) values, AR (Aspect Ratio) values and salience for the five ceramic vessels from experiment 2: A Middle Neolithic 4000–3000 BC; B Final Neolithic 2800–2500 BC; C Bell-Beaker–Bronze Age 2300–1800 BC; D Iron Age II 400–200 BC; E Iron Age III 100 BC–0 (Graphics: A. Rodríguez-Paz).

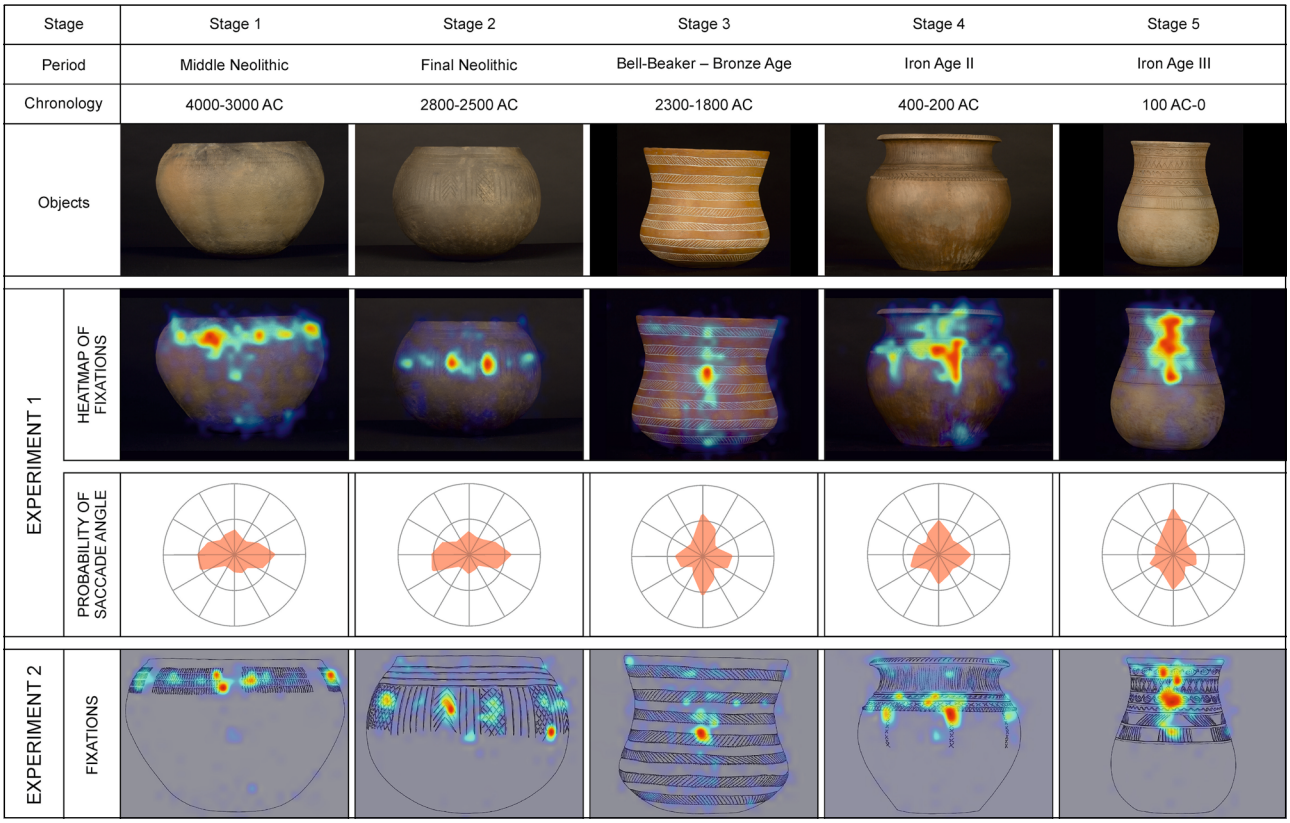

Fig. 8. Visual behaviour induced by each ceramic object, according to the data from experiment 1 and 2 (Graphics: A. Rodríguez-Paz).

For the purpose of improving our methodology, it was interesting to confirm that the visual behaviour in response to photographs versus drawings was the same (Criado-Boado et al. 2019, supplementary fig. ED15), which is why in Exp2 and 3 we worked only with drawings. Nor did we find any differences when analysing only ceramics (Exp1 and Exp2), or when working with them among a variety of images (faces, objects, geometric shapes …) (Exp3) that are looked at very differently than ceramics.

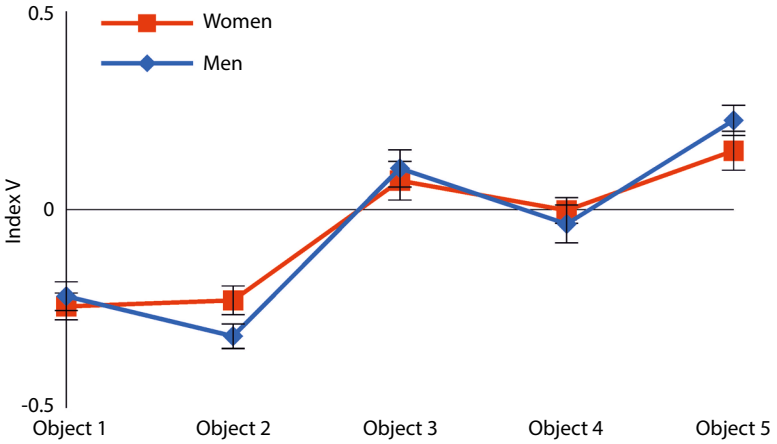

Fig. 9. Gender differences in Vi (Vertical index) (after Criado-Boado et al. 2019, supplementary fig. ED11).

Further analysis showed that Vi records a lot of information about the way the object is observed. The application and interest of this result (as well as others derived from these experiments) transcends the disciplinary field of archaeology. A linear discriminant analysis of Vi allowed us to show its ability to predict which vessel is being observed, something that highlights the influence or dominance that the object exerts on perception (Criado-Boado et al. 2019, 4 fig. 2B). In other words, the decoration predetermines the visual orientation in such a decisive way that the observed vessel can be identified from the visual movements. This was an important empirical consequence of the work because it significantly exemplifies the objects' agency in the cognitive process.

Indeed, the AR and the decoration of each object contribute to directing visual exploration in a synergistic way, but each does so differently using a different mechanism. Figure 10 reflects this by showing the variations to which we subjected the original series of vessels in Exp2 and 3 and by comparing it with other artificial forms. In neutral (i. e. undecorated) conditions the AR and Vi fit together quite well (Criado-Boado et al. 2019, 5 fig. 3A and

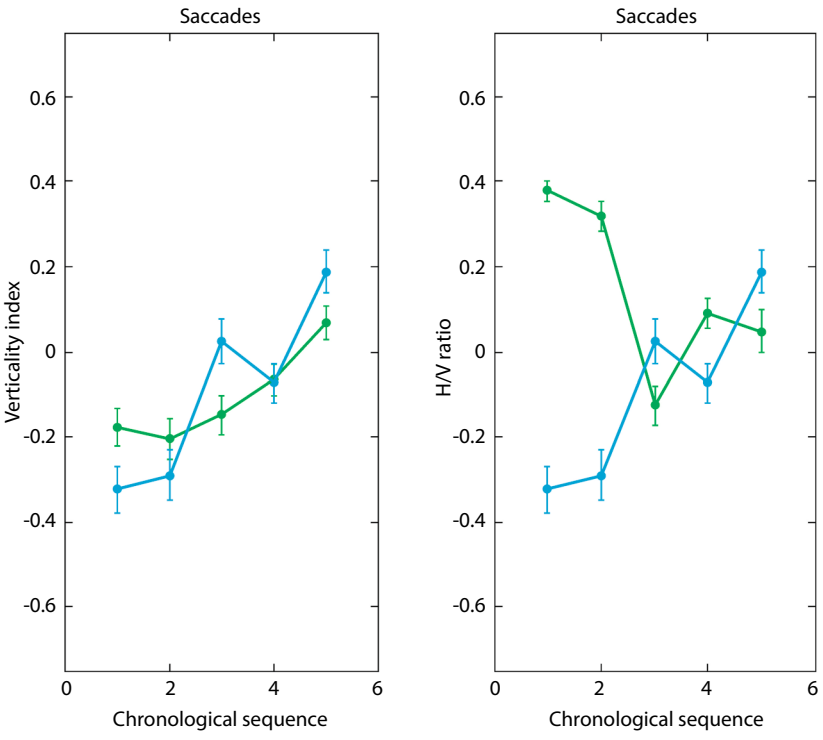

Fig. 10. Vi (Vertical index) of the ceramic objects in column 3 of Figure 11 (blue) compared to, on the left, the Vi of the same objects without decoration (green, column 4, Fig. 11) and on the right, the Vi of the objects positioned sideways (green, column 8, Fig. 11) (Graphics: A. Rodríguez-Paz).

Fig. 11. Saccade direction in the images of experiment 2. Columns 1, 2 and 3 are original objects; the others are variations of these (upper part from Criado-Boado et al. 2019, supplementary fig. ED9; graphics: A. Rodríguez-Paz).

supplementary fig. ED17). The same can be said when analysing the AR and visual response of the same geometric shape with different H/V ratios (Criado-Boado et al. 2019, 5 fig. 3B). In this case the horizontal or vertical elongation of the shape reduces or enlarges Vi, which clearly indicates the degree of indeterminacy between Vi and AR. It is significant that, despite this, the effect of decoration modifies the powerful impact of the overall shape (measured through its AR) on the orientation of visual exploration. This effect is confirmed by Figure 11 which, based on Exp2 data, exemplifies how the interchange of shapes and decorations between vessels causes Vi to be substantially modified. The artificial changes allow us to see how the visual behaviour is influenced by the specific decoration of each ceramic style. For example, by placing a metope scheme decoration from the Final Neolithic on an Iron Age III jar (image 5.5), the visual response becomes horizontal. Contrarily, when a Bell-Beaker decoration is placed on an Iron Age II vessel, a vertical response is strengthened. This can be seen very clearly in the images of column 8. Placing the ceramic vessels sideways, the visual response follows the decoration pattern.

Exp1 and 2 confirmed that the first saccade tends to be to the left and upwards. When the decoration is in the centre of the vessel or at the bottom, the gaze is directed towards it, but the initial delay is longer. This bias raises interesting questions about the possibility that the first saccade is conditioned by reading habits. Despite the fact that there may be such a pre-programmed visual behaviour, for the material agency analysed in this paper it is relevant to see how the configuration of materiality imposes the rhythm of the viewing pattern. Exp3 showed that, when introducing the ceramics among other very different shapes, this bias of the first saccade is lost and generally at the beginning the observer keeps their sight in the centre. This shows that, depending on the task, the observer changes their attention and willingness to look. In an experiment with ceramics only, the observer adopts a visual attitude analogous to that of reading, as if they were initially disposed to "read" the decoration. However, the material strength of the decoration ends up altering and rendering this bias irrelevant. In an experiment such as Exp3 with many images of very different types, the observer adopts a more neutral attitude, fixing their gaze a priori on the centre, in the expectation of what they will find in the shown figure. However, once again, it is most relevant that in spite of this the analysis of Vi of the ceramic images presented in Exp3 shows the same behaviour as that documented in Exp1 and 2.

Interpretations

These results have implications that go beyond the findings discussed in the original paper. On the one hand, they allow for archaeological and social interpretations of materiality and cognition that complement the starting hypotheses (listed in the Scope section). On the other hand, they offer new perspectives on the 'themes' we outlined in the first section of this text.

From an archaeological and prehistoric point of view, these results confirm that *the material structure of pottery*, beyond its intrinsic visual information, *determines the way it is looked at*. It is an important methodological result that, through Vi, which compares the percentage of vertical and horizontal saccades, we can characterize the way of looking, in other words, the visual behaviour that each type of ceramic style generates. These data support the importance and influence of decoration in the visual process, something that becomes particularly clear when, for the purpose of the study, we interchange shapes and decorations in order to identify the relative effect of each one of them. One could say that Vi follows the AR of the vessels initially, but differs from the latter when decoration is introduced. In other words, it could always be assumed that it is the shape of a Bell Beaker vessel that leads the eye vertically. But if we add the Bell Beaker decoration to a bowl-shaped vessel whose decoration would lead the eye horizontally (Style 1), the preferred direction of observation of this vessel changes. And if we add the decoration of said bowl-shaped vessel to the Bell Beaker vessel, it is viewed more horizontally.

Decoration is what directs Vi and makes it an accurate expression of the pattern of the gaze adjusted to each object. Furthermore, it makes Vi increase over time and does so, in our analytical series, through the replacement of horizontal formal patterns (Styles 1 and 2) by vertical patterns (Style 3) and of these by vertically hierarchical patterns (Style 4 and especially Style 5). The results therefore confirm the initial hypotheses and show that each vessel, i. e. each ceramic style, contains information that equally conditions the way of looking of very different observers and all of them in the same way. This is shown by the fact that no differences of gender, group or other types of biases can be appreciated. It follows that *the individual observer does not produce particular patterns of looking*, as their subjective

charge is less important in recognizing and orienting the way in which they explore the vessel than that imposed by the materiality of the vessels. In other words, the pattern of exploration is the same regardless of the observer's individual bias.

From a completely different empirical perspective, these findings would confirm the studies on identity and individuality that Almudena Hernando (e. g. 2012) has been proposing for years. Indeed, materiality exhibits group patterns that are actively influenced by them. In the experiment presented here we address this question when we find that the visual response is analogous to the formal pattern of each material style. Indeed, we detected a symmetrical change in material forms and ways of looking at them over time, which is also related to the type of social relationship of past groups, be it more egalitarian or hierarchical. In this sense, if we take into account the archaeological context of the vessels in our study, a record that stretches from the Middle Neolithic to the Late Iron Age, we can see a tendency towards a greater or lesser verticalization of the gaze according to the greater or lesser degree of social hierarchy. The *materiality produces an active effect on visual perception* which is imposed on the observer regardless of their position in the sample. This effect depends on the internal articulation of the material form that arranges the visual field in strips where significant variations occur either in the horizontal or in the vertical plane. Therefore, the observations of this work lead us to a basic substrate of the perceptual process that remains independent of individual differences. This is partly because it is predetermined by the biology of the visual system itself (something that neuroscience admits as a constant given the strong biological and energetic constraints on visual processing), and partly because it is overdetermined by materiality. This would be the main implication of Criado-Boado et al. 2019, for while it is well accepted in visual cognition studies that biological determinants are constant in the human species, the major innovation of our approach is highlighting that the artificial world that humans generate, what we do, also determines how that biological predetermination is brought into play. In this article we can go a little further than before and point out that the incidence of biology and materiality in visual perception should not be confused with a supposed mechanistic determinism of the cognitive process.

We do not believe that such a mechanistic determinism has a place in this research. Although it may seem contradictory to point out the determinations of cognition and at the same time deny determinism as an explanation of the cognitive process, this is an apparent paradox. It only holds if we think of these determinations on a single undifferentiated and excessively rigid plane – as if the mind were a closed electrical circuit. On the contrary, the development of neuroscience and artificial intelligence points out that the indeterminate character of the brain's automatisms, far from resembling routine mechanism, contains immanent contradictions (David Bates, cit. Malabou 2017, 143). The historicity of materiality, so extensively studied by archaeology, in fact reinforces this indeterminacy of visual cognition from its variations, transformations and disappearances throughout history and, by extension, this anchoring of the mind in the world and history.

There is a simple way of showing the indeterminacy of the cognitive process. A very popular experiment in visual illusions identifies the effect of the "blind spot" of the retina or "papilla" on visual perception. This would be the area of the retina from which the optic nerve emerges and in which there are therefore no cones or rods to pick up visual sensations. When we place two fingers in the position shown in Figure 12, close one eye and with the other observe the finger on the opposite side, we immediately notice that the finger corresponding to the closed eye disappears. This happens because in this position it is exactly aligned with the papilla. Even if we lower the finger, it remains invisible, and we still see the same. However, this

experiment also shows us something surprising: instead, we see what is behind the finger. The reason why we do not see the finger but what is behind it (which we are not actually seeing) is that the visual cognition process fills in the expected image by making a projection of the dominant statistics in its environment (He/Davis 2001). As the finger stands alone, our mind cannot replace it. However, the shapes and colours behind the finger that are an extension of what is around it, are reconstructed in the visual cognitive process even though no actual visual sensations of that part of the observed field are detected. This is confirmed when instead of one finger we hold up several (the experiment was actually carried out with drawn stripes). In this case the visual processing interpolates the finger that we do not see. Properly speaking, we see without looking because the brain assumes probabilities based on the visual context to reconstruct the processed images. The blind spot experiment shows that what we call visual perception is not an exclusive result of the sense of sight, but that it brings into play a cognitive process that is traversed by mediations (including the perceived materiality) that condition our gaze. We can say that the brain reserves a degree of uncertainty about what it sees that is inseparable from the automatisms of the cognitive process. The philosopher Catherine Malabou (2017, 145) speaks of an internal dialectic between automatism and the resistance of automatism to itself. We can join her and say that biology neither subtracts from nor closes the way to history. At this point we can add that the biological conditions of the gaze make it an open cognitive process. Knowing these limits is in fact a way of confronting old epistemological problems. This is something we can explore in further detail.

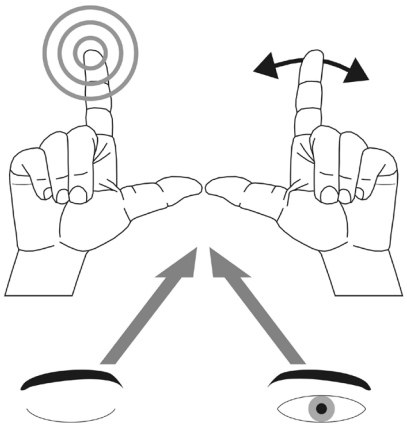

Fig. 12. Blind spot experiment (Graphics: A. Rodríguez-Paz).

Seeing is not just a matter of perceiving sensations, but of processing them cognitively. This is the consequence of a biological system developed to reduce the energy costs of visual processing: our retina has a resolution equivalent to 105 megapixels, but the optic nerve transmits compressed images of one megapixel to the brain. In fact, if the brain were to process original-sized images, humans would need a brain the size of an elephant, consuming two tonnes of sugar a day. Hence, in order to regenerate quality images in the mind, previous low-resolution images have to be decompressed by increasing their resolution based on statistical models of the visual world that the visual part of the brain has generated based on the memory of experience. Luis Martínez and colleagues (2014), who have studied this phenomenon, draw an analogy between cognitive image processing in the brain and the way image decompression works in a digital camera. This, in other words, means that we can see without looking because we have 'memory' (we return to this in the next section).

One way of approaching the synergistic interaction between world and cognition, and anticipating its implications in terms of rationality, is to think of embodiment as a symmetrical process of the mind in the world and the world in the mind that occurs because *perception depends on the statistics of the world*, on the sum of material features of the world that are in one way or another measurable and numerically expressible (Field 1987; Ruderman 1994; Sigman et al. 2001; Torralba/Oliva 2003). Our research corroborates how perception is the education of attention (Ingold 2007) through materiality. Furthermore, the possibility that the form of both the material and the way of looking are related to social complexity (more horizontal in less complex societies, more vertical in hierarchical societies), introduces an additional dimension to this web of interactions between world, perception and cognition. Moreover, it introduces a new understanding of the processes of embodiment. The justification for this correlation is implicit in the main result that these experiments highlight. For if there is a world-matter-mind relation, it includes a world that is not only natural (it does not only encompass light, geomorphology, terrain, physiography, vegetation), but incorporates human modifications too. That is, the world as constituted by

physical and social domains, by natural and social relations, and by materialities that are naturally and culturally produced. The statistics that reflect the visual world include the constructed world, a world that is not only natural but also human-made and human-transformed. This evidence points to an active and plural relationship between living, doing and thinking. In this sense, we should not confuse this reasoning about the matter-world-mind relation with the "to build, to inhabit, to think" connection highlighted by Martin Heidegger (1994a). This research does not, of course, delve into any transcendental metaphysics of being and its revelations. In this paper we show instead that ways of looking are also ways of thinking, forms of rationality, which in turn can be distinguished because visual behaviour is not so much a process guided solely by the senses or perceptions, but a cognitive process, which involves the mind and thus shapes and builds it on a historical foundation[7].

We could therefore assume that the people, who originally made and used the studied ceramics, would have looked at the vessels in a very similar way to the present-day subjects who are confronted with them. Whether familiar with them beforehand or not, they would have looked at the pottery in a very similar way. This will certainly be the objection that will be made against this work from the fields of archaeology and the humanities. Being good social disciplines, they are obliged first and foremost to account for the human exception and to think about social reality in and for itself, not from reductionist positions. But we believe that *our consequences go beyond the traditional* (i. e. modern) dichotomous views between individual and society, or biology and culture. Without underestimating the semantic and individual charge that the objects had for the people who made and used them, the conclusions we reach here point to a more basic level of perception, which does not rule out other anthropological and social readings of materiality, but allows us to understand the interaction of its configuration and agency with the cognitive process and the active role it plays between the latter and the world. Therefore, we can assume that the visual response of present-day humans and the original subjects would not have varied much, since ultimately that response is mediated by an indisputably common biology and by one materiality – which is the same.

In other words, a relevant criticism of the research is to point out that the way pottery is viewed by today's subjects does not necessarily indicate anything about how it was viewed by the subjects who were its original authors and users. Our response is that, excluding the individual subject from the equation, we are left with a process with three actors: biology, materiality and socio-cultural context. Knowing that two are constants (biology, which has not changed, and materiality, which is the same) and knowing that the third not only changes, but is largely unknowable to us in its entirety, we can deduce that visual behaviour is the same (because it depends primarily on the first two) even if the meaning of what is seen has changed culturally[8]. Our work confirms the former, but future research is needed on the latter[9].

Perspectives

This research highlights the interest of neuro-archaeological studies of relatively recent times, indicates important cognitive changes in a few hundred years or generations, and raises several other issues.

Firstly, it shows that the ways of looking at each object (visual behaviour) are constant and regular for all objects of the same style. In other words, *style drives visual behaviour* (materiality drives visual behaviour). The way of looking is determined by what we have done before, by the process of materialisation. This is probably the clearest conclusion of this work. From these physiological and cognitive results (eye movements) we can thus gain

7 It should be noted that this study poses a limit to traditional phenomenology by addressing the biological constants that condition perception. The phenomenological self (the one guided by the senses) would not correspond to the process of visual cognition of the gaze, since this process cannot be analysed from a perspective that starts from the first person as the central axis of the study. The process of visual cognition is neither perceptible by oneself nor reducible to the behaviour or experience of the subject, hence to analyse it requires a tertiarisation of the analysis (i. e. a third-person analysis). This is what the eye-tracking technique allows us to do. Going beyond the phenomenological self opens the way to a historical understanding of perception, since on the one hand it allows us to analyse the way of looking at objects independently of the subject who looks (it allows us to study the gaze in the past), but it consolidates the need for historical research to account for the relationships and historical conditions that have determined this way of looking (it allows us to study the formation of the gaze).

8 To settle this issue within the limitations of archaeology, which is unaware of the pattern of rationality involved in the construction of meaning by societies and individuals that we cannot fully access, we would have to see whether it is possible for the force of materiality to convey a meaning that can be interpreted cross-culturally. This would require an "archaeology of the thing" which, through the formal and contextual study of things, would allow access to the "thing" itself, to the issue or argument behind it, to its historical meaning in short. This path is not impossible, but it is another path, which would require the revision of the epistemological bases of the discipline and the adjustment of neurobiological conclusions to the open indeterminacies of human anthropology. Today, the philosopher Markus Gabriel (2016) is working more or less successfully along these lines, which the aforementioned Catherine Malabou (2016) is reworking from another position, starting from the fundamental problem of epigenesis.

9 After this article was submitted, we learned of the approval of a project that two of the authors (FCB and LMM), together with Andy Clark and Johannes Müller, submitted to the ERC (European Research Council) Synergy Grant 2020 call for proposals. This project is entitled "Material minds, Exploring the interactions between predictive brains, cultural artefacts, and embodied visual search" and explores in part the questions addressed in this text. Its acronym is XSCAPE, for the reasons given below. It is funded with 10 million EUR and will take place from October 2021 to 2027.

the most objective proof so far of the long-standing archaeological thesis stating that changes in materiality co-evolve with and are in accordance with changes in social structure. Co-evolution here means that changes in one of the factors go hand in hand with changes in the other.

Thirdly, this article points out that the ways of looking at each style are also a social form. That is to say, *the gaze and style are part of the characteristics of socio-cultural formation*. This happens precisely because style is the materialisation of the power system (Prieto-Martínez 2009; 2017), that is, of the social form.

In the fourth place, the fact that our visual representations are the result of a cognitive process based on sensations processed against the statistical model of the world made by the visual part of our brain, points to another perspective: both what we feel and our way of looking (visual behaviour) are intrinsic to our cognitive processes (and models). That is, *consciousness* (in other works one of the authors speaks of 'rationality', Criado-Boado 2012) *and the world are symmetrically interwoven*. Consciousness embodies the world, and the world emulates consciousness.

A further noteworthy implication of these results is that it allows us to nuance an aspect of the anthropological approaches that are based on alternative ontological models. Basically, these are based on a different conceptualization of the concept of representation in order to defend that in certain societies there is no separation between reality and the image, but that the latter maintains the status of an active entity (a presence) in continuity with the world. The crisis of this form of representation is a process that acquires weight in the West from the Baroque period onwards, when the objectification of the epistemological process vis-à-vis the world begins. Michel Foucault (1968) identified this process in "The Order of Things" with the passage from the Renaissance to the Classical period. The relation to idols, the image conceived not as an abstract representation of being, but as an extension of it, is an enduring example of this conception prior to modern representation. The ontological turn, by conceiving objects as 'actants' in Bruno Latour's (2005) terminology, evokes these alternative ontological traditions and, in part, lends a theoretical veneer tailored to the active character that technological and digital progress has intensified in things. More generally, these theoretical elaborations and processes are indicative of the changes now facing a modernity in which its constitutive features – the ontological representation of things being one of them – are being re-mobilised. That is why the new conceptions of representation postulated by the most radical theories of embodiment in the cognitive sciences share this turn of representation as presence by showing that representation is not something purely abstract, autonomous in the mind, but involves sensory and motor information provided by material reality itself. In one way or another, these ideas are part of an epochal frame of mind. This work corroborates this conceptualization, for it shows how objects, rather than being inanimate things or representations of entities and values that in prehistoric archaeology are not usually given, are actors that provoke reactions, act on behaviour, predetermine it and guide the cognitive process in one way or another. However, we shy away from models that, in our view, tend to be excessively automatic and gimmicky in their explanations (see Reynoso 2015). Assuming a different notion of representation, as advocated by the ontological turn, requires mediations capable of regulating the different capacities of action recognized in objects, rather than a new speculative formulation of the ontological status of the world – this is the programme on which a part of philosophy and the social sciences has embarked, more attentive to the yields of academic immediacy than to the tempestuous paths of research. It is precisely this work that encourages us to take things seriously by means of a method that sheds light on a fundamental aspect of the

historical process, namely the weight of materiality in human patterns of action and cognition. It is also a way of rethinking the old thesis that technology is an important factor in human thinking, an idea without which the processes of innovation and technological change of any historical phase cannot be understood.

In the fifth place, this research shows that memory plays a basic role in the perceptual process, and in the meantime broadens our understanding of this key concept for the social, historical and cognitive sciences. The *relationship between social memory, individual memory and memory as a neural process* is not clear. Standard neuroscience does not concern itself much with memory and tends to consider anything other than individual memory as a false memory. But in reality all memory is false. The moment something is recalled, a plasticity advantage is produced that introduces other effects into the 'memory'. As Oliver Sacks (2013) said, memory is dialogic and arises not only from direct experience but from the intercourse of many minds. The study of the mechanisms of perception shows that the representations we construct with our senses of the world depend more on cognitive processes than on direct perceptual stimuli. What we see (as well as what we hear, what we feel with our senses) is the result of a cognitive processing in which the sensory stimuli are completed on the basis of a previously created model of the world. This means that what is actually perceived depends at least as much on memory as it does on perception. The studies of visual cognition that we discuss in this paper show that this memory is constructed from the external stimuli of the world, i. e. experience. As this world is not a natural world, but a world bound by social relations, a produced space, a material world constructed by humans, what humans do gives rise to these models and to memory. Put in this way, 'cerebral' memory, individual memory and the social construction of both are unified. Social memory would therefore be akin, if not identical, to the other two. It seems, then, that harmonizing the 'three memories' is easier than we might have expected. But this also explains why memory is so uncertain. Rather than being a constant, memory is the result of our social and individual updates of our tradition and previous experience in relation to the circumstances of the world around us. The archaeologist Laurent Olivier (2008) draws similar conclusions in his reflections on the material memory of archaeological remains. In this case, from a completely different position, memory is also the result of the physical alterations that affect the archaeological object. These alterations end up forming an accumulation of traces of the past, the study of which is essentially an activation of the memory embedded in them. We have tested the literalness of this phenomenon in the visual cognition processes of materiality.

Ultimately, this work paves the way for future research claiming that *the social form guides consciousness and consciousness reconstructs the social form*. With these observations in mind, Karl Marx's phrase "life is not determined by consciousness, but consciousness by life" acquires new meaning, or rather recovers the meaning Marx intended, but was confused by other readings[10]. Thus, the long-standing issue of the persistence of rational models and the resistance to change in pre-modern human cultures receives an alternative horizon of understanding. A horizon from which we can glimpse that in the mechanisms of visual cognition we have a historical constant that allows us to approach the biological pre-programming of human beings and how this constitutes consciousness. Without thus incurring in a naturalistic reductionism, as these processes have always been actively incorporated into socio-cultural formation. This would also explain why social tradition, cultural styles and culture itself are so inert and tend to permanence and continuity. Change is presented with resistance, born from the need to generate models of a world that does not yet exist.

[10] Brown 2014a, 110–111. – Or, as this author comments on Marx's visual metaphor in another passage: "… with the figure of the *camera obscura*, Marx both explains consciousness' inversion of reality and offers a potential remedy for this inversion, which can be corrected as completely as the brain corrects the inversion of images on the retina. For Marx, the logic of ideology's inversion of reality is just as absolute, just as necessary and inevitable, as the retina's inversion of what is seen. In both cases, reality is not randomly distorted but is turned precisely upside down. Moreover, what appears initially as metaphor or homology between vision and consciousness collapses into identity as a contiguity unfolds between the two processes Marx is analysing. Ideology is not merely comparable to visual process but is itself about ways of seeing" (Brown 2014b, 78–79).

The extended version of the second hypothesis of this paper was, in fact, the starting point for this research. We started from a proposition developed through a series of investigations in landscape archaeology that allowed us to postulate specific models of conception of space behind landscape forms and, more generally, specific forms of materiality in different societies (e. g. Criado-Boado/Villoch 1998). We then observed that these patterns seemed to correspond to specific ways of looking (Prieto-Martínez et al. 2003, 179–180 fig. 22–23). The reiteration of this spatial structure in different codes and material contexts of the same socio-cultural formation led one of the authors (FCB) to define this ideal model as 'xscape', i. e. the constant form underlying different types of landscape, skyscape, soundscape, emotionalscape, mindscape, … 'xscape' (Criado-Boado 2014). The postulation of these kind of structures was a purely theoretical construct, although it followed a rigorous interpretative method (more influenced by structuralist than hermeneutic methodologies). It derives from a heterodox application of the anthropologist José Luis García's approach (1988). This consists of isolating the concrete models of each material or empirical code analysed, comparing them with each other in order to recognize, through the regularities between them, the ideal concrete model and, thus successively, to reach an ideal generic model (or structure) (Criado-Boado 2012, 211 fig. 31). This made it possible to define a theoretical-conjectural model for a research programme in landscape archaeology beyond the study of the environment, uses and symbolism (specified in Criado-Boado 2012). However, the confirmation or acceptability of the basic proposal, which advocates structural compatibility between the cultural concept of space, landscape forms (including architecture, material culture and domestic and individual space), and the characteristics of each social formation, was still unresolved; hence the concerns of some critics. Therefore, deeply convinced that if this model worked it had to leave some kind of imprint on cognition, when one of the authors (FCB) began to discuss this approach it was suggested by another (LMM) that this hypothesis could be confirmed through an eye-tracking methodology. This was the starting point to empirically validate an older hypothesis.

As was mentioned at the beginning, this hypothesis was already included in the article "Megaliths, space, thought" (Criado-Boado 1989). The current research allows us to see that the structural relationship between materialities, mind and world is based on the fact that the cognitive processing of sensory experience (vision first and foremost, but not exclusively, as the same will happen with the other senses) creates a relationship between the social system and the world. The point is not that form determines how we look. The main issue is that it does so in a way that is homologous to the characteristics of the social system in which it is produced. Since the way of seeing is related to the mind, to rationality, what this shows is that *social manners actively influence the forms of rationality through the perception of the material forms they produce*. What we really have here is a loop in which all these processes (thinking, doing, seeing) actively feed back into each other on foundations that, being indeterminate and contingent (because they are not determined by biology), include the layers of history. Perhaps, the fact that this is so confirms the error of having substantiated each of the processes as if they were distinct elements, instead of basing their separation on an analytical question that does not dissolve the basis of their relationship. In this way, this work maintains the commitment to construct an archaeology that is capable of elucidating research problems of general interest on the basis of old archaeological theses based on new problems and methods that are not used by more canonical archaeological research. Archaeology can and must take this path in order to better serve the public to which it is beholden.

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