Cognitive Foundations in Visual Art: Understanding Brain Responses to Color, Spatial Depth, and Form

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Abstract: This study explores the intersection of art and human cognition, focusing on how cognitive primitives influence the perception of visual stimuli in art. By employing novel ceramic mosaics, including mosaics that fuse Roman and Islamic artistic traditions, we examine the universal and predictable nature of cognitive primitives akin to physical laws in human perception. Our methodology involves participant interaction with these mosaics, enabling an analysis of cognitive responses to various artistic elements. Our findings reveal that cognitive primitives play a foundational role in visual perception, particularly in interpreting art. Participants' responses to the mosaics consistently aligned with theoretical expectations of cognitive primitives, demonstrating predictable patterns of perception across different visual stimuli. This supports the notion that certain aspects of visual perception are universally inherent, reducing the need for extensive experimental validation typically seen in cognitive science. The study contributes to the understanding of human cognition through art. It underscores the importance of cognitive primitives in visual perception and aesthetic experience, suggesting broader implications for fields like education, therapy, and design. The paper proposes future research directions to further explore cognitive primitives in different sensory modalities and artistic expressions, and their application in practical fields. This research presents a novel perspective on the predictability and universality of human cognitive responses to art, offering insights into the fundamental ways we process and interpret visual information.

Keywords: Cognitive Primitives, Art Perception, Visual Stimuli, Human Cognition, Ceramic Mosaics.

1. INTRODUCTION

Art serves as a unique mirror reflecting the intricate paths between human cognition and emotion. This study investigates elements of this interplay, examining how art becomes a language that the brain deciphers, revealing fundamental aspects of our cognitive processes and emotional responses.

The world of art has long been explored for expressing the intangible aspects of human experience. It transcends the boundaries of mere visual appreciation, engaging our cognitive faculties and emotional landscapes in profound ways. This intersection of art with cognition and emotion underscores a complex narrative of human experience, where art becomes a tool for understanding the depths of the human psyche. The colors, forms, and spaces in art evoke a spectrum of responses, highlighting how deeply intertwined art is with our mental and emotional fabric (Ishizu & Zeki, 2014; Ramachandran & Hirstein, 1999; Winner & Hetland, 2000).

Central to this study is the exploration of cognitive primitives in art perception. Cognitive primitives are the foundational elements of human perception, akin to building blocks through which we interpret the world around us. In the context of art, these primitives guide our understanding and appreciation of aesthetics. This research aims to study how these basic cognitive functions, when engaged with artistic stimuli, contribute to the formation of our aesthetic experiences, shaping our interpretation and emotional reactions to art (Chatterjee et al., 2010; Livingstone, 1988; Winner & Hetland, 2000).

To investigate these concepts, the study employs a novel methodology using ceramic mosaics. These mosaics, designed to use simple geometry and to blend elements of Roman and Islamic art traditions, serve as a canvas for examining how the human brain processes visual information. The Roman tradition, known for its detailed representational art, is juxtaposed with the Islamic tradition's emphasis on abstract geometrical patterns. This contrast provides a rich context for observing how cognitive primitives operate in interpreting complex visual stimuli, offering insights into the cognitive underpinnings of art perception.

The primary objective of this work is to study how the human brain processes visual stimuli presented through art. This entails an examination of how different elements such as color, form, and spatial arrangement are perceived and interpreted by the brain. Understanding these processes is crucial for comprehending how art influences and is influenced by cognitive functions. It also involves exploring how these visual elements in art trigger specific neural pathways and how they contribute to the overall experience and understanding of an artwork (Boccia et al., 2016; Kanwisher et al., 2023; Pelowski et al., 2017; Zeki, 2017).

The second objective is the study of the cognitive underpinnings that give rise to aesthetic experiences. It explores the cognitive processes that are activated when individuals engage with art. This includes investigating how aesthetic appreciation is formed, the role of emotional responses in art perception, and how cognitive and emotional responses to art are interconnected. The goal is to establish a formal understanding of the cognitive mechanisms that drive our appreciation and interpretation of art, shedding light on why certain artworks resonate profoundly with our senses and emotions (Chatterjee & Vartanian, 2016; Pearce et al., 2016; Skov & Nadal, 2020).

2. THEORETICAL FRAMEWORK

This section establishes the theoretical foundation of the study, exploring the concept of cognitive primitives, the traditional interplay between cognitive science and art, and evaluating existing theories in art perception along with their limitations.

2.1. Introduction to the Visual Experience of Artwork

The visual experience of observing artwork initiates when light-based visual stimuli from the artwork enter the eye and are captured by the retina. This light is transformed into neural signals, which are then transmitted to the brain. Here, in regions such as the visual cortex, these signals are decoded, allowing the observer to perceive shapes, colors, and patterns. This initial phase of visual processing is critical, as it sets the foundation for the subsequent, more complex interpretative stages of art perception. The brain's interpretation of these neural signals is influenced not only by the physical properties of the artwork but also by the viewer's unique visual processing abilities and neurological health.

The stimuli received from viewing an artwork do not exist in isolation but interact dynamically with the viewer's past visual experiences. This interaction occurs in the brain's higher-order processing areas, where memories, knowledge, and prior experiences are stored. As the brain interprets the current visual stimuli, it retrieves relevant past experiences and knowledge, allowing the viewer to contextualize and understand the artwork. This interplay generates a rich tapestry of sensations and emotions, influenced by personal memories, cultural background, and learned associations with certain visual elements. It is this deeply personal and subjective aspect of art perception that allows different individuals to experience the same artwork in vastly different ways.

The interplay between current visual stimuli and past experiences leads to an iterative process in art perception. As the viewer continues to observe the artwork, their brain repeatedly cycles through phases of receiving new visual information, processing it, and comparing or integrating it with past experiences and knowledge. This iterative cycle deepens the viewer's engagement with the artwork, often leading to new insights, emotional responses, and interpretations with each successive viewing. Consequently, the observer's visual attention is continuously refocused on the artwork, allowing for a more profound and nuanced appreciation. This process is dynamic, with the potential to evolve as the viewer's perspective and context change over time (Overlan et al., 2017; Piantadosi et al., 2016; Picon et al., 2019).

2.2. Modeling Visual Stimuli as Digital Signals

In this approach, the visual stimuli from an artwork are conceptualized as a digital signal, which is characterized primarily by two aspects: resolution and the quality of light. Resolution, measured in terms of the number of pixels, determines the level of detail that the visual system can perceive. A higher resolution corresponds to a more detailed and nuanced representation, enabling a finer appreciation of the artwork's intricacies. The quality of light in each pixel is described through three key parameters: hue, saturation, and luminance. Hue refers to the color itself, saturation to the intensity or purity of the color, and luminance to the brightness or lightness. This characterization allows for a precise understanding of how the visual stimuli are structured and how they convey the artistic message. By breaking down the artwork into these fundamental components, researchers can more effectively analyze how the brain processes and interprets different visual elements within a piece of art.

The nature of the visual stimuli – light – and its interaction with distance plays a pivotal role in this model of art perception. Light is the medium through which the visual information of the artwork is conveyed to the viewer. The way light interacts with the materials and textures of the artwork significantly influences how the artwork is perceived. Distance affects the resolution of the signal received by the eye; as the distance between the viewer and the artwork changes, so does the resolution of the visual stimuli. Closer proximity allows for higher resolution and more detail to be discerned, while greater distances might reduce the level of detail perceived. This interaction between light and distance is crucial for understanding how viewers perceive art and what details they focus on. By considering these factors, researchers can gain insights into how different visual conditions influence the art viewing experience and how the brain adapts its processing based on these variables (Beaty et al., 2016; Dissanayake, 2015; Wilms & Oberfeld, 2018).

2.3. Study of Visual Primitives

Visual primitives are defined as the foundational, low-level cognitive processes responsible for the initial processing of visual information. These processes handle the basic parsing of pixel information, including interpreting the dimensions of light such as hue, saturation, and luminance within each pixel. They represent the most elemental form of visual perception, operating at a level where the brain begins to construct a coherent visual representation from raw sensory data. Visual primitives act as the initial interpreters of the visual world, translating simple pixel-based information into meaningful visual cues.

In the context of art perception, visual primitives play a crucial role in how we perceive and interpret various elements within an artwork. They allow us to discern transparency in solid elements, perceive depth in a two-dimensional representation, identify the sources and interplay of light within the artwork, detect implied movement, and recognize forms and objects. For instance, through visual primitives, the brain can interpret a series of color gradients and shapes as a transparent veil over a solid object or understand the perspective cues that give a sense of three-dimensionality. These processes are integral to the way viewers engage and derive meaning from art, forming the basis of our aesthetic experiences.

Visual primitives are intricately linked to broader cognitive processing mechanisms. They serve as the bridge between the raw data received by the visual system and the higher-level cognitive functions such as memory, emotion, and conceptual understanding. These primitives lay the groundwork upon which more complex cognitive processes build, transforming basic visual signals into rich, multifaceted perceptual experiences. For example, the recognition of a form within an artwork may begin with visual primitives but is enriched by the viewer's memories, emotions, and cultural context. This interconnectedness underscores the role of visual primitives as not just passive receivers of visual information, but as active contributors to the holistic process of visual perception and cognition.

2.4. Implications for Understanding Art Perception

An in-depth understanding of these cognitive processes, particularly how visual primitives operate, significantly enhances our comprehension of the aesthetic experience of art. By dissecting the cognitive underpinnings of how we perceive and interpret art, we gain insights into why certain artworks resonate deeply with us, evoke particular emotions, or capture our attention. This understanding transcends the subjective interpretation of art, providing a more structured explanation of our aesthetic experiences. It helps in unraveling the complex interplay between sensory input, cognitive processing, and emotional response, which collectively shape our appreciation and understanding of art. Such knowledge not only enriches the viewer's experience but also provides artists and creators with a deeper understanding of how their work may be perceived and interpreted.

The insights gained from understanding these cognitive processes have a wide range of practical applications. In art education, this knowledge can be used to develop more effective teaching strategies that align with how students naturally perceive and process visual information, thereby enhancing their ability to appreciate and create art. In art therapy, understanding the cognitive basis of art perception can guide therapeutic techniques, using art as a medium to access and influence cognitive and emotional processes for healing and expression. For artists and art creators, these insights offer invaluable guidance in the creation of visual art, allowing them to craft works that effectively communicate intended messages, evoke desired emotions, or challenge viewers' perceptual processes.

This understanding can also be applied in design fields such as advertising, architecture, and user-interface design, where visual perception plays a crucial role in the effectiveness of the design.

3. METHODOLOGY

In this study, we use mosaics as a medium to explore and understand human cognitive processes in art perception. The methodology employed is centered around the design and assembly of ceramic mosaics, where each piece is crafted to investigate how combinations of visual elements can elicit complex perceptual experiences. Central to this methodology is the use of tessellas, the fundamental building blocks of mosaic art. This section outlines the approach used in selecting and characterizing these tessellas, their arrangement to produce desired visual experiences, and the overall composition strategy.

The tessella will serve as the fundamental unit in the art of mosaic creation. These units will vary in geometric shapes, including squares, triangles, hexagons, and other forms, providing a diverse toolkit for creating complex designs. The shape and size of each tessella will be varied as part of the design, with common dimensions ranging from small 5 mm pieces to larger ones of 20-30 mm. The choice of geometry and size of each tessella plays a crucial role in the overall composition of the mosaic, influencing both the detail and the texture of the final artwork.

The color of each tessella will be a design factor in the creation of a mosaic. We defined the color through a combination of hue, saturation, and luminance. The hue determines the base color, saturation indicates the intensity or purity of the color, and luminance reflects the brightness or darkness of the tessella. This attention to color allows for the creation of specific visual effects within the mosaic, such as depth, movement, and light interplay. The strategic choice of color in each tessella contributes to the overall aesthetic and perceptual experience of the mosaic, enabling artists to manipulate visual perceptions and evoke emotional responses in the viewer.

For this study we developed a visual language based on the simple language of tessellas. We constructed the language by defining the shape and color of the tessellas. Geometric shapes range from basic squares and triangles to more complex forms like hexagons, each chosen for their ability to fit together and create specific patterns and textures. The size of the tessellas was also a critical factor, with varying dimensions selected to control the level of detail and scale within each mosaic. Color properties, including hue, saturation, and luminance, were defined for each tessella, enabling a rich palette that could be used to evoke specific moods, atmospheres, and visual effects. This structured approach to selecting and combining these elements formed the basis of the study's mosaic design language, providing a framework within which the mosaics could be systematically constructed.

The development of this visual language played a critical role in the precise design of the mosaics. By having a set of predefined parameters for the tessellas, the study was able to manipulate visual elements with a high degree of control. This allowed for the creation of mosaics that were aesthetically pleasing and functionally aligned with the study's objectives. The arrangement of tessellas according to their shape, size, and color facilitated the production of specific perceptual effects, such as the illusion of depth, the representation of light sources, or the simulation of movement. This language provided a method to systematically explore how different combinations of visual elements could influence perception and cognitive processing, making it an essential tool in the study's exploration of art perception through mosaic design.

Figure 1, https://shorter.me/U-M1i, shows two examples of the mosaic language of monochrome embedded octagons, with limited access to effects of transparency, light, depth, and form.

Figure 2, https://shorter.me/U-M1i, shows two mosaics created with this language, producing visual experiences of transparency, source and light distribution, sense of depth and space, and form.

Figure 3, https://shorter.me/U-M1i, shows two examples of the mosaic language of monochrome polygons in Roman-Islamic style, with limited access to effects of transparency, light, depth, and form.

Figure 4, https://shorter.me/U-M1i, shows a mosaic created with this language, producing visual experiences of transparency, source and light distribution, sense of depth and space, and form.

The design of the mosaics in this study was focused on eliciting specific key visual experiences, integral to understanding the cognitive processing of visual art. These experiences include the perception of transparency, the detection of a light source, the sensation of depth or 3D perception, and the representation of form within the mosaic. Each of these experiences was considered to explore how visual stimuli are processed and interpreted by the human brain in these four areas.

For transparency, the design involved creating layers of color gradients and playing with the opacity of tiles to mimic the effect of light passing through a translucent material. In depicting a light source, we focused on the arrangement of colors and luminance gradients to simulate the way light illuminates and casts shadows, creating a sense of a directional light source within the artwork. To achieve the illusion of depth or 3D perception, the mosaics utilized varying gradients of luminance and saturation. For the representation of form, the mosaics combined shapes and colors in such a way that familiar forms and figures emerged from abstract patterns, engaging the viewer's ability to recognize and interpret visual representations. It is important to note that while individual tessellas alone do not independently create these effects, it is their strategic combination and juxtaposition within the mosaic that leads to the emergence of these complex perceptual phenomena. This approach highlights the synergy between individual visual elements and the overall composition, demonstrating how simple units can come together to create rich, multifaceted visual experiences in art.

We created two distinct types of mosaics, each designed to create a unique set of visual experiences encompassing the four paradigms: transparency, light, depth, and form. The first type of mosaic utilized a square-shaped basic tessella with an embedded octagon. The mosaics represented abandoned concrete buildings where bright color sheets of silk floated in the wind. The second type of mosaic represented a fusion of Roman and Islamic mosaic traditions. These mosaics maintained a consistent geometric structure across each segment, with variations only in color. The thematic focus for this type was the depiction of glass and metal buildings by the sea. Here, the goal was to combine the distinct aesthetics of Roman representational art and Islamic geometric abstraction, while also encapsulating the four paradigms.

The methods employed in creating these mosaics were both innovative and collaborative, involving a cross-section of the university community, including personnel, students, professors, and administrators. The tiles for the mosaics were crafted using the sublimation technique, a process that allowed for the precise transfer of intricate designs and colors onto the tiles. This method proved essential in accurately depicting the visual paradigms intended in each mosaic. The creation of the mosaics was not just a physical assembly of pieces; it was an interactive and dynamic process, enriched by continuous conversations among the participants. As they worked on crafting the tiles and assembling the mosaics, participants shared their visual perceptions and experiences, providing immediate, real-time feedback on the emerging artwork. These discussions were integral to the project, as they offered insights into the subjective experiences of the creators, complementing the reactions of viewers who later observed the completed works. This qualitative amalgamation of perceptions and experiences from both creators and viewers formed the basis for evaluating the effectiveness of the mosaics in conveying the intended visual paradigms, thus bridging the gap between artistic creation and cognitive perception.

4. RESULTS AND DISCUSSION

In this study, a qualitative research method was employed to gain a deeper understanding of the participants' and viewers' experiences with the mosaic artworks. This approach aligns with the key elements of qualitative research, which emphasizes exploring rich, descriptive data to understand complex phenomena. We conducted oral interviews allowing us to capture the nuanced perceptions and responses of individuals in their own words. This method enabled an exploration of the subjective experiences of art perception, resonating with the qualitative focus on understanding the 'how' and 'why' behind observed phenomena. This approach allowed for an exploration into how the combination of simple visual elements in the mosaics led to complex perceptual experiences. The subjective nature of art perception, with its reliance on individual cognitive and emotional processing, lent itself well to this qualitative approach. This methodology underscores the importance of subjective experience in art perception and aligns with the established practices of qualitative research in capturing and interpreting complex, nuanced data (Charmaz & Belgrave, 2012; Denzin & Lincoln, 2008; Guba & Lincoln, 1994; Hammarberg et al., 2016; Ioannidis, 2016; Wasserstein et al., 2019).

The results of this qualitative study on art perception through mosaic artworks revealed several key findings. Participants and viewers consistently reported experiencing the intended visual paradigms of transparency, light source detection, depth, and form representation when observing the complete mosaics, despite these elements not being apparent when viewing small clusters of individual tessellas.

In terms of transparency, participants described a sensation of seeing through layers or veils when observing certain mosaics. They noted changes in color and texture that simulated the experience of looking at translucent materials, despite the inherent solidity of the mosaic tiles.

Regarding the perception of light, viewers frequently commented on how certain arrangements of tiles created the illusion of a light source within the mosaic. This was particularly noted in areas where color gradients and luminance shifts were employed, giving a sense of natural illumination and shadow.

Depth and three-dimensionality were also prominently experienced. Participants described feeling a sense of physical space and depth in the mosaics. The strategic placement of tessellas and variations in shape and color were key contributors to this effect.

Finally, the representation of form was a common theme in the feedback. Viewers were able to identify shapes, figures, and objects within the mosaics, attributing this recognition to the collective arrangement of simple geometric tessellas that, together, formed recognizable patterns and images.

Participants reflected on their experiences, noting the complexity of perceptions that emerged from seemingly simple elements. These reflections were rich with descriptions of emotional responses, aesthetic appreciation, and personal interpretations, providing understanding into the cognitive and emotional processes involved in art perception.

Thematic analysis highlighted patterns in how different visual elements were perceived and interpreted. This analysis underscored the effectiveness of the mosaic designs in eliciting the targeted visual experiences and offered insights into the underlying cognitive processes at play.

These findings contribute to a broader understanding of how complex visual experiences can be evoked through the strategic combination of simple visual elements. The study's results suggest that even basic geometric shapes and colors, when arranged thoughtfully, can engage sophisticated cognitive mechanisms, leading to rich and varied perceptual experiences in art viewing.

These results are indicative of the success of the mosaic design in achieving its intended objectives. The study's approach, relying on the basic elements of color and shape in tessellas, demonstrated that when these elements are combined thoughtfully and strategically, they can create a rich tapestry of visual experiences far beyond the capability of their individual parts. The effectiveness of the mosaics in eliciting the targeted visual paradigms highlights the intricate cognitive processing involved in visual perception, where the whole is perceived as significantly more than just the sum of its parts. This outcome validates the design approach of the mosaics and provides insightful implications for understanding how complex visual experiences are constructed from simple visual cues in art perception.

This study's exploration of the cognitive processing involved in art perception through mosaic artworks holds broader implications for both cognitive science and art studies. In cognitive science, the findings contribute to a deeper understanding of how complex visual experiences, such as depth, light, transparency, and form, are constructed from simpler visual cues. This aligns with cognitive science's broader goal of deciphering the mechanisms of perception and interpretation within the human brain. For art studies, the research offers valuable insights into how different elements of artwork - color, shape, and composition - interact to evoke specific perceptual and emotional responses. It underscores the significance of art as a medium through which cognitive processes can be observed and understood, providing a unique lens to study human cognition. Additionally, this study bridges the gap between theoretical knowledge and practical application, suggesting new approaches for artists and educators in crafting artworks and curricula that engage with the viewer's cognitive processes. Overall, by illuminating the interplay between art and cognitive processing, this study enriches our understanding of art perception and contributes to the broader discourse in both cognitive science and art studies.

5. FUTURE DIRECTIONS

Future research in the field of cognitive primitives presents several promising directions. One key area involves exploring these primitives across different sensory modalities. This could include investigating how cognitive primitives operate in auditory experiences and comparing these with visual modalities. Another avenue is examining the role of cognitive primitives in various forms of artistic expression beyond visual art, such as music, dance, or literary art, to understand their universal applicability across artistic disciplines. Researchers could also focus on developing more refined models that detail the interaction between cognitive primitives and more complex cognitive processes. Such models could provide a deeper understanding of how basic perceptual building blocks contribute to higher-order cognitive functions, thereby enriching both cognitive science and art studies.

The findings of this study have implications for fields like education and design. In education, particularly in art education, an understanding of cognitive primitives can lead to the development of teaching methods that are more aligned with these fundamental perceptual processes. This approach could enhance students' learning experiences by leveraging their innate cognitive capabilities. For designers working in visual media, architecture, or product design, applying knowledge of cognitive primitives can lead to the creation of designs that resonate more deeply with users, by appealing to their intrinsic perceptual and cognitive tendencies. Understanding these primitives can guide designers in making more impactful, emotionally engaging, and user-friendly designs.

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People interested in learning more about the theoretical aspects of this work, and the practical aspects of the implementation of the art installation (photographs, videos, concepts, links, participants, etc.) can find more information on these web pages: https://www.ehu.eus/en/web/gmm/ceramic-drawing-2023.prague https://www.ehu.eus/en/web/gmm/ceramic-drawing-2023.warsaw https://www.ehu.eus/en/web/gmm/ceramic-drawing-2023.calais

REFERENCIAS

Beaty, R. E., Benedek, M., Silvia, P. J., & Schacter, D. L. (2016). Creative cognition and brain network dynamics. *Trends in cognitive sciences*, *20*(2), 87-95. https://doi.org/10.1016/j.tics.2015.10.004

Boccia, M., Barbetti, S., Piccardi, L., Guariglia, C., Ferlazzo, F., Giannini, A. M., & Zaidel, D. W. (2016). Where does brain neural activation in aesthetic responses to visual art occur? Meta-analytic evidence from neuroimaging studies. *Neuroscience & Biobehavioral Reviews*, *60*, 65-71. https://doi.org/10.1016/j.neubiorev.2015.09.009

Charmaz, K., & Belgrave, L. (2012). Qualitative interviewing and grounded theory analysis. *The SAGE handbook of interview research: The complexity of the craft*, *2*, 347-365. https://doi.org/10.4135/9781452218403

Chatterjee, A., & Vartanian, O. (2016). Neuroscience of aesthetics. *Annals of the New York Academy of Sciences*, *1369*(1), 172-194. DOI: 10.1111/nyas.13035

Chatterjee, A., Widick, P., Sternschein, R., Smith, W. B., & Bromberger, B. (2010). The assessment of art attributes. *Empirical Studies of the Arts*, *28*(2), 207-222. https://doi.org/10.2190/EM.28.2.f

Denzin, N. K., & Lincoln, Y. S. (2008). Introduction: The discipline and practice of qualitative research. https://psycnet.apa.org/record/2008-06339-001

Dissanayake, E. (2015). "Aesthetic primitives": Fundamental biological elements of a naturalistic aesthetics. *Aisthesis. Pratiche, linguaggi e saperi dell'estetico*, *8*(1), 6-24. https://doi.org/10.13128/Aisthesis-16203

Guba, E. G., & Lincoln, Y. S. (1994). Competing paradigms in qualitative research. *Handbook of qualitative research*, *2*(163-194), 105. https://psycnet.apa.org/record/1994-98625-005

Hammarberg, K., Kirkman, M., & de Lacey, S. (2016). Qualitative research methods: when to use them and how to judge them. *Human reproduction*, *31*(3), 498-501. https://doi.org/10.1093/humrep/dev334

Ioannidis, J. P. (2016). Why most clinical research is not useful. *PLoS medicine*, *13*(6), e1002049. https://doi.org/10.1371/journal.pmed.1002049

Ishizu, T., & Zeki, S. (2014). A neurobiological enquiry into the origins of our experience of the sublime and beautiful. *Frontiers in human neuroscience*, *8*, 891. https://doi.org/10.3389/fnhum.2014.00891

Kanwisher, N., Khosla, M., & Dobs, K. (2023). Using artificial neural networks to ask 'why'questions of minds and brains. *Trends in Neurosciences*, *46*(3), 240-254. https://doi.org/10.1016/j.tins.2022.12.008

Livingstone, M. S. (1988). Art, illusion and the visual system. *Scientific American*, *258*(1), 78-85. DOI: 10.1038/scientificamerican0188-78

Overlan, M. C., Jacobs, R. A., & Piantadosi, S. T. (2017). Learning abstract visual concepts via probabilistic program induction in a Language of Thought. *Cognition*, *168*, 320-334. https://doi.org/10.1016/j.cognition.2017.07.005

Pearce, M. T., Zaidel, D. W., Vartanian, O., Skov, M., Leder, H., Chatterjee, A., & Nadal, M. (2016). Neuroaesthetics: The cognitive neuroscience of aesthetic experience. *Perspectives on psychological science*, *11*(2), 265-279. https://doi.org/10.1177/17456916156212

Pelowski, M., Markey, P. S., Forster, M., Gerger, G., & Leder, H. (2017). Move me, astonish me… delight my eyes and brain: The Vienna Integrated Model of top-down and bottom-up processes in Art Perception (VIMAP) and corresponding affective, evaluative, and neurophysiological correlates. *Physics of Life Reviews*, *21*, 80-125. https://doi.org/10.1016/j.plrev.2017.02.003

Piantadosi, S. T., Tenenbaum, J. B., & Goodman, N. D. (2016). The logical primitives of thought: Empirical foundations for compositional cognitive models. *Psychological review*, *123*(4), 392. https://doi.org/10.1037/a0039980

Picon, E., Dramkin, D., & Odic, D. (2019). Visual illusions help reveal the primitives of number perception. *Journal of Experimental Psychology: General*, *148*(10), 1675. http://dx.doi.org/10.1037/xge0000553

Ramachandran, V. S., & Hirstein, W. (1999). The science of art: A neurological theory of aesthetic experience. *Journal of consciousness Studies*, *6*(6-7), 15-51. https://philpapers.org/rec/RAMTSO-5

Skov, M., & Nadal, M. (2020). A farewell to art: Aesthetics as a topic in psychology and neuroscience. *Perspectives on Psychological Science*, *15*(3), 630-642. https://doi.org/10.1177/1745691619897

Wasserstein, R. L., Schirm, A. L., & Lazar, N. A. (2019). Moving to a world beyond "p< 0.05". *The American Statistician*, *73*(sup1), 1-19. https://doi.org/10.1080/00031305.2019.1583913

Wilms, L., & Oberfeld, D. (2018). Color and emotion: effects of hue, saturation, and brightness. *Psychological research*, *82*(5), 896-914. https://doi.org/10.1007/s00426-017-0880-8

Winner, E., & Hetland, L. (2000). The arts in education: Evaluating the evidence for a causal link. *Journal of Aesthetic Education*, 3-10. https://www.jstor.org/stable/3333636

Zeki, S. (2017). Art and the brain. In *The Brain* (pp. 71-103). Routledge. https://doi.org/10.4324/9781351305204