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Progress and Promise in Neuroaesthetics

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We review progress and highlight open questions in neuroaesthetics. We argue that computational methods can provide mechanistic insight into how aesthetic judgments are formed, while advocating for deeper collaboration between neuroscientists studying aesthetics and those in the arts and humanities.

The field of neuroaesthetics, in which the neural mechanisms underlying the experience, appreciation, and judgement of works of art are subject to inquiry, is perhaps one of the most mature of all the nascent research domains at the interface of neuroscience and the arts and humanities. There is a long intellectual tradition focused on elucidating the psychological mechanisms underlying aesthetics that goes back at least to the middle of the nineteenth century (Fechner, 1876), whereas an explicit focus on the neural basis of aesthetics started to emerge at the turn of the twenty-first century (Zeki, 2002), perhaps in tandem with the maturation of neuroimaging methods that rendered measurement of the human brain during aesthetic processing and experience possible for the first time. Here we briefly discuss some of the key questions that have been investigated to date and highlight some of the outstanding issues: how reward and pleasure operate in aesthetic processes and how to disentangle individual differences from broadly perceived aspects of a stimuli and evolutionarily conserved neural pathways.

Early studies in the field of neuroaesthetics focused on identifying the brain regions involved in aesthetic liking or pleasure. A key finding of these studies is that many brain regions associated with aesthetic liking (such as the ventromedial prefrontal cortex and the ventral striatum) were also fundamental in processing rewards. This pattern of results has been widely reported in the literature for an array of stimuli that can invoke an aesthetic experience, including viewing of pictures and drawings (Kawabata and Zeki, 2004) or listening to pleasant music (Salimpoor et al., 2011). Thus, the component of aesthetic processing that involves positive affective responses to a stimulus appears to display very similar neural substrates as stimuli that act as rewards like money or pleasant tastes and odors. This finding places stimuli that evoke aesthetic pleasure firmly in the realm of other rewarding stimuli. In the reward field, evidence has been presented to suggest that a region of medial prefrontal cortex is involved in a domain-general manner in encoding the value of different rewards (Chib et al., 2009), consistent with the implementation of a "common currency" for reward value in that brain area. Intriguingly, an ostensibly similar region of medial prefrontal cortex has been found to be involved in representing subjective liking across a diverse array of stimuli (Lebreton et al., 2009).

A fundamental open question about the role of pleasure in visual aesthetics and its neural basis concerns whether pleasure constitutes a single "output" from aesthetic experience or whether the aesthetic response is more complicated. It is possible that positive aesthetic experience goes beyond that which can be measured by a single scale that ranges from low to high. For instance, in the reward field, a distinction has been made between the subjective experience of "wanting" that is elicited by the prospect of obtaining a reward and "liking" that follows from its consumption (Berridge, 1996). Perhaps aesthetic experience too involves a combination of these distinct components of reward processing. Furthermore, aesthetic experience may tap into a broader and richer class of emotional responses involving not only positive but also negative affect. One can find joy pleasurable, but melancholy can also be bittersweet.

Yet another important question concerns the role of individual differences in aesthetic experience. Studies of aesthetic judgments about landscapes, visual art, and poetry suggest that both behaviorally and at the neural level there are distinctions in how human beings respond to and process the pleasures of beauty. One way of understanding this is by looking at "shared" pleasure—the degree to which individuals might agree that an object is pleasurable. In general, the more an object appears to be the product of culture (a painting, for example), the more people disagree about how much pleasure they take in looking at it (Vessel et al., 2018).

What might make some kinds of objects seem more universally beautiful and others less so? Part of the answer relies on the varying contributions of experience, culture, and inheritance. For example, variance partitioning (dividing consistency in individual responses into what is repeatable across individuals and what seems to be more idiosyncratic) has demonstrated that the perception of beauty in human faces, even in identical twins, relies on both individual taste and genetics (Germine et al., 2015). fMRI studies have shown that some aspects of individual taste rely on the default mode network (Vessel et al., 2012). In general, we note, individuals understand highly moving aesthetic responses as positive. Perhaps the least well explored, but ultimately most challenging problem in neuroaesthetics, is to gain an understanding about how the brain comes to reach a particular aesthetic judgment about a stimulus in the first place, which

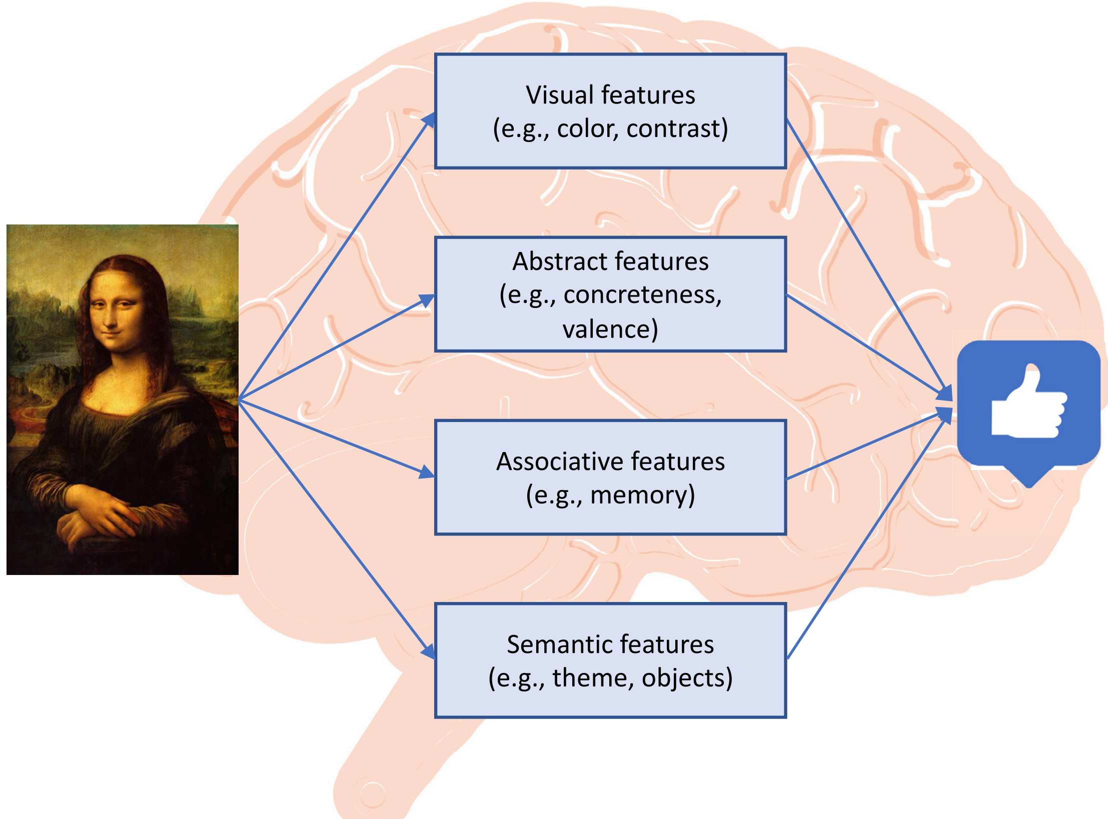

Figure 1. Schematic of a Feature Integration Model

A stimulus (e.g., visual art piece) is broken down to various features that are shared among visual stimuli. These features are then integrated with relative weights to construct a subjective aesthetic value for the stimulus. Variation in the integration weights assigned over features across individuals can capture personal tastes.

could be argued to be the "hard" problem in neuroaesthetics. In a nutshell, the problem concerns understanding how the brain decides whether a particular stimulus is aesthetically pleasing or not. In essence, this is a computational problem and one for which it ought to be possible to utilize the tools of modern computational neuroscience and machine learning to resolve.

Within the psychology of aesthetics, a number of features or properties have been proposed as being associated with positive aesthetic judgments, some of which are argued to have acquired import through evolutionary adaptations. Chatterjee et al. (2010) identified a number of features that were hypothesized to be related to aesthetic judgment at least as pertaining to visual art, which essentially correspond to both low- and high-level classifications about an image, such as its color composition, whether it is abstract or concrete, whether it is dynamic or still, whether it depicts a positive or negative affective situation, and so on (see also Vaidya et al., 2018). Thus, according to this idea, any stimulus can be broken down into objective components that describe its content, leaving open the possibility that some of these components can be identified as playing a role in driving judgments of aesthetic valuation (Figure 1). This idea resonates with modern neuroscience, in which the brain's sensory systems, most notably the visual system, is known to extract elementary features from a stimulus and then combine these features to make higher-level features that can support cognitive judgments about objects such as what the object is (a dog, or a cat, or a bicycle), what location it is, whether it is moving, and so on. Aesthetic valuation of an object can be seen in this light as another form of high-level judgement about an object that is computed from elementary features in a hierarchical manner.

In our opinion, a very fruitful direction to understanding the computational basis of aesthetic valuation will be to engage in a reductionist fractionation of the elementary features of a stimulus and assess the role that these features collectively play in driving aesthetic valuation. Using this feature-based approach, it may be possible to empirically define the specific features that the brain uses to compute aesthetic judgments. Some of these features will be objective properties of a stimulus, e.g., a stimulus will be red, or it will be green; it will be dynamic or still. However, even though the features themselves might be objective properties, the extent to which they are used by individuals to create aesthetic judgments doesn't have to be objective—instead, the way such features get weighted might vary across individuals. For instance, some individuals may like abstract art, and others concrete. The same individual might also weigh those features differently based on a difference in context. Crucially, relative weighting over features can allow for variation in personal taste even among features that are objectively defined. Therefore, this simple feature-based framework can enable one to study cultural and social differences in human aesthetic tastes.

Yet the feature-based approach need not rely exclusively on objective features. As we alluded to earlier, the extent to which a particular artwork is judged relevant to an individual suggests that some features themselves may have subjective qualities unique to that individual. For instance, a particular piece of art might remind a person of an experience they had with their grandmother at age 6. This element of the evaluation of the stimulus is not going to be an objective property of the image that is divorced from the perceiver. Thus, to gain a comprehensive understanding of how the brain comes to produce an aesthetic judgment, we argue it will be important to characterize both objective and subjective evaluative features of a stimulus.

The proof in the pudding of this approach would be that it should be possible to identify specific brain regions involved in representing the features involved in aesthetic evaluation and in determining how those features get combined to yield an overall aesthetic judgment. Framed this way, the process of understanding the formation of aesthetic preferences is not just a problem of sensory neuroscience but also touches many other aspects of the brain's cognitive apparatus, including memory, emotion, learning, and decision-making. Studying such an aesthetic computation by deep convolutional neural networks is also a promising approach, as network models have been shown to capture key aspects of the brain's visual processing.

We conclude by considering the value of collaboration between those in the arts and humanities and the neurosciences in order to advance understanding of this topic. How can the neuroscientific study of aesthetics benefit from collaborative input from the humanities? One way is that those in the arts and humanities are expert in describing the complexity and nuance of human experience. While neuroscientists have a tendency to simplify the problem for the sake of tractability, such as for example by reducing aesthetic pleasure to a single scale, those in the arts and humanities might blanch at such oversimplification, perhaps urging the need to gain a richer characterization that better captures the full complexity of human aesthetic experience. Furthermore, philosophical input into the study of neuroaesthetics may help to stress test and ultimately bring coherence to theories about aesthetic computation.

On the other hand, neuroscience brings to the field of aesthetics the enormous power of the reductionist approach to understanding brain function that, for all its downsides, has been enormously successful in yielding an understanding of the building blocks of human cognition. Engaging in productive reductionism such as that outlined in the computational approach to feature selection discussed above will undoubtedly generate insights into the neural computations underlying aesthetic experience, provided the limitations of this approach necessitated by the simplifying assumptions are kept in mind when interpreting the results. Ultimately, finding the right approach to disentangle what belongs to individuals, what emerges from cultures, and what is the product of millions of years of evolution requires learning across the disciplines.

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