Is Beauty in the Eye of the Beholder or an Objective Truth? A Neuroscientific Answer

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1 Introduction

What makes something beautiful? The enigmatic nature of beauty has preoccupied philosophers and scientists alike since antiquity. For philosophers, short of defining beauty, the principal question has been to discover where it lies. Specifically, is beauty a quality of objects (objectivist view) or does it come from within the beholder (subjectivist view)? From the sixth century BCE until the eighteenth century CE, most philosophers fell in the objectivist camp [25]. For example, both Plato and Aristotle held that things were beautiful if they respected certain mathematical forms. Later, in the Middle Ages, Augustine argued that things gave delight because they were beautiful, not the other way around. The philosophers and artists of the Renaissance extended these classical principles, placing beauty in mathematical properties of objects like proportions, perspective, symmetry, and compositional geometry [1]. It was not until the end of the seventeenth century that philosophers such as Locke, Hume, and Kant started to think of beauty in a more subjective manner [25]. Locke, for instance, pointed out that experiencing color, a major aspect of beauty, was unique to the individual [18]. In turn, Hume, one of the biggest proponents of the subjectivist view, wrote, “beauty of things exists merely in the mind which contemplates them” [12]. The debate over where beauty lies continues to this day and has spilled over beyond the realm of philosophy into the fields of cognitive and neural sciences. For instance, in recent years, the field of neuroaesthetics has seen a significant growth [8]. Increasingly, neuroscientists are beginning to use modern tools to see whether they can give insight into the age-old question of beauty.

The objectivist viewpoint of beauty has considerable support from scientific studies across the globe. These studies explore whether measurable features of stimuli can account for people’s preferences. An example of one such feature is symmetry. Research shows that symmetry is highly preferred across cultures, genders, and age groups [5]. Additionally, this symmetry preference exists across many domains, whether it be in faces, foods, buildings, inanimate objects, or technological interfaces [31]. Therefore, symmetry is one of the most prominent examples of an objectively defined characteristic of beauty. Other features such as balance, color, fractality, complexity, and curvature also point toward the existence of objective, universal standards [17]. For example, complexity is known to follow a universal “inverted U” shape in relation to beauty and liking [4]. Hence, individuals prefer moderate amounts of complexity to something very simple or extremely complex. At a higher conceptual level, features such as prototypicality, novelty, and semantic content also show universality of preference. For example, people prefer more prototypical faces, shapes, cars, and paintings, and prefer figurative as compared to abstract art [19, 33]. The reason for such universality can be explained by our shared evolutionary history and consequently because of similar processing mechanisms in our brains (discussed in greater detail in Sect. 2).

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For every instance of objective standards discussed above, there are equally as many examples of subjectivity [20]. These examples exist at both the socio-cultural and the individual levels. An example of cultural differences comes from a study comparing British and Egyptian students' preferences of graphic stimuli [5]. This study found that the Egyptian group overall gave higher ratings to all types of symmetry (horizontal, vertical, and rotational). However, Egyptians liked less complex versions of symmetry than the British counterparts did. Similarly, a study of fractality preference found that European and African populations picked images with greater complexity than did people from North America or Central Asia [29]. These differences can likely be attributed to different levels of exposure as well as the culturally dependent values of those variables. For example, in Middle Eastern countries the holy sites are often adorned with symmetric patterns, increasing the cultural value of some types of symmetry [5]. Higher cognitive factors such as visual content processing can also be culturally modulated [22]. For instance, when looking at a visual scene Westerners tend to focus on focal objects, while East Asians tend to have a more holistic approach. This difference is evident in eye-tracking studies as well as in functional brain imaging [11]. Unsurprisingly, these differences also influence aesthetic preferences, with Westerners preferring images with central objects and less contextual information as compared to East Asians [20]. These differences also likely stem from cultural beliefs and values as they are evident in cognitive domains outside of visual processing as well [22].

So far, we have seen evidence for universal (objective) as well as cultural (subjective) dependence of visual aesthetic preferences. In the next two sections, we look at these differences from the perspective of neuroscience. We begin with discussing a cognitive psychology theory and show that one of its consequences is the existence of objective aspects of beauty (Sect. 2). We then discuss how subjectivity arises from the networks in the brain responsible for learning and motivation (Sect. 3).

2 The Processing Fluency Theory and Objectivity in Beauty

Certain physical properties of objects in the world are important for survival regardless of one's environment or social setting. For example, as social beings, detecting and recognizing human faces quickly and correctly is valuable to us. Therefore, through evolution, our brains have developed specialized neural structures to process information from faces [14]. Similar neural circuitry also exists for certain visual properties such as symmetry, complexity, and balance [9, 13, 32]. As a result, barring some cultural variability, the neural and cognitive mechanisms underlying the processing of these features are largely similar across individuals. Consequently, our cognitive responses to these features, including liking and disliking, are also largely similar, thereby creating a semblance of objectivity through universality [17]. A prominent theory in Neuroaesthetics, the processing fluency theory, links the evolutionary basis of these universals to aesthetic values. In this section, we discuss this component of processing fluency theory and present evidence from our research showing its applicability to aesthetics.

The processing fluency theory states that the easier it is for a perceiver to process the properties of a stimulus, the greater its aesthetic response will be [24]. Therefore, the theory depends on both the dynamics of the perceiver as well as the object. This theory has four assumptions. However, for our purposes, we will only consider the two primary ones. First, the processing fluency theory assumes that objects differ in their fluency. Specifically, the extent to with what ease one perceives and conceptualizes an object defines how fluent it is. Therefore, this assumption implies that a component of fluency relies on the constituent features of the object. Examples of these features include symmetry, proportion, balance, contrast, and complexity. What mediates the fluent processing of these variables? As discussed above, such variables have dedicated neural circuitry. Consequently, this allows these variables to be processed more efficiently and "fluently". In this way, evolutionarily important variables which have their own real-estate in the brain form a major part of? processing fluency. Second, the processing fluency theory assumes that fluency is hedonically marked, so objects with higher fluency are perceived more positively than are those with lower fluency. Why are these features and their fluency hedonically marked? The answer has to do with evolution and the nature of perception. Our only access to the surrounding world is perceptual estimation through our senses. We use these estimates to make decisions about the world (sometimes life or death). Therefore, it is highly advantageous for evolution to associate rewards with those features in the outside world, improving their estimates and letting us make better decisions. For example, detection of imbalance in visual scenes is necessary for survival, because lack of balance codes for visual outliers, and may thus indicate danger or other features of interest [13]. Therefore, the amount of imbalance in a visual scene indicates its salience and will thereby attract our visual attention. This allows us to immediately spot and direct our attention to, for example, a lion hiding in the bushes. Overall, the assumptions of the processing fluency theory have considerable support from several psychophysiological studies in cognitive psychology, but also in marketing, technology, education, and other fields [24]. It is evident that processing fluency, in part due to its evolutionary roots, can account for a wide variety of psychological phenomena related to preference. However, we wondered if it could explain aspects of aesthetics in art as well. Specifically, we were interested to see if certain universal biases would emerge in artworks.

To understand whether the processing fluency theory could account for certain aspects of visual art, we measured symmetry, balance, and complexity in Early Renaissance Portraits [2]. We chose these variables because of their evolutionary importance, dedicated circuitries in the brain, and prominence in art theory [3, 9, 13, 31]. To give a detailed example, consider the case of symmetry. Symmetry is of high evolutionary importance due to its prominence in important biological structures such as faces, plants, and body plans (Fig. 1a). In biological contexts symmetry is often a signal of good health and disruption of symmetry can signal genetic or natural abnormalities [27]. Apart from its importance in the natural world, symmetry is one of the defining principles in art (Fig. 1b). Additionally, symmetry serves as a "perceptual glue" allowing efficient grouping of visual input to separate objects from backgrounds [31]. Considering how much important visual information symmetry can deliver, it is not surprising that it has dedicated neural structures in the brain. Functional magnetic resonance imaging (fMRI) studies have shown that areas early in the visual processing hierarchy are activated when looking at symmetric stimuli (Fig. 1c—[26]). Not surprisingly, therefore, the processing of symmetry is fast and fluent [32]. Consequently, the processing fluency theory accounts for symmetry being a hallmark of visual aesthetics.

Based on the premises of the processing fluency theory, we predicted that master painters would show biases toward maximizing fluency variables [2]. To test this prediction, we first developed computational measures for symmetry, balance, and complexity. We then measured these fluency variables in three types of images: portrait paintings, carefully posed photographic portraits, and spontaneously snapped photographic portraits (Fig. 2). All portraits included only one subject. The portrait paintings were from master artists from the Early Renaissance, using a variety of mediums. The posed control portraits consisted of carefully framed frontal, angled (45°), and profile (90°) pictures of volunteer participants. With the carefully posed frontal pictures, we could ask whether the master painters achieved optimal amounts of symmetry and balance. In turn, the spontaneously snapped pictures were meant to have no artistic intent. Hence, they allowed us to figure out whether painted portraits showed more balance and symmetry than those obtained spontaneously.

Comparing spontaneous portraits with those by master painters from the Early Renaissance gave support to the processing fluency theory. An example of one such comparison appears in Fig. 3a. Here we measured the amount of vertical bilateral balance in each different type of image. There are many definitions of pictorial balance, for our analyses we defined balance as the difference between the total pixel intensities across the vertical midline of the image. Our results show that the mean index of imbalance for Renaissance portraits is lower than is that for spontaneous portraits. Hence, Renaissance master painters were not making spontaneous portraits, but composing their painting to increase balance. These results stemming from the analysis of balance were similar to those for the index of symmetry [2]. As for complexity, the analysis separated information based on pixel intensities from spatial organization. There are many definitions of complexity, all which essentially measure the amount of information [9]. We defined Complexity of Order 1 as the total amount of variability in pixel brightness, for example, a uniform image compared to static noise, with more variability leading to greater complexity. We then defined Complexity of Order 2 as the spatial organization of those pixels, such as a detailed image versus a uniform shape or an object, where greater detail would lead to greater complexity. To do this analysis, we first converted the images into grayscale. The results showed that the Complexity of Order 1 of canvases was less from those of photographs because of the limited choices of oil pigments and hence less variability in intensities [2]. However, we found that master painters may have consciously or subconsciously compensated by increasing Complexity of Order 2. They did so by making paintings more realistic, thus increasing their level of detail. This gives more information to the viewer, which increases its fluency as predicted by the processing fluency theory.

However, master painters did not make balance, symmetry, and complexity as large as possible. For example, Fig. 3a shows that by carefully posing subjects frontally, one can achieve indices of imbalance that are lower from those seen in Early Renaissance portraits. Careful posing yielded similar results for symmetry [2]. Are these results in violation of the processing fluency theory, which predicts a maximization of fluency variables such as balance and symmetry? Intriguingly, art historians have observed that Early Renaissance master painters tended to avoid frontal portraits, thereby reducing perfect balance and symmetry [23].

A probable reason for why Early Renaissance master painters did not maximize balance, symmetry, and complexity was the competition of these variables against each other. For instance, if one increases the symmetry in an image, it becomes less complex [9]. In a symmetric image, knowing the color of a point on the left side of the canvas automatically tells us the color of the equivalent point on the right side. Therefore, the amount of information or complexity falls as the symmetry (or balance) increases. This reduction of complexity would explain why Early

Renaissance painters tended to avoid frontal poses. These painters might want to increase complexity to give more information about their subject. That variables like complexity compete against symmetry or balance means that each master painter must decide how to equilibrate them. Some may emphasize the complexity, while others may choose to highlight balance and symmetry. Figure 3b shows how three different master painters from the Early Renaissance equilibrated balance and complexity individually. If one thinks of the possible values of balance and complexity as spanning a space, then individual painters exist in different portions of this space. We conceptualize the full space as multidimensional. It would include variables like complexity, balance, and symmetry, but also others that influence aesthetic values, such as color and texture. We call the possible values of these variables the “neuroaesthetic space”. We propose that preferences existing in different regions of the neuroaesthetic space are a major component of individuality in artistic production and appreciation.

In conclusion, our work supports the processing fluency theory and thus, the existence of some universal aesthetic variables such as balance, symmetry, and complexity, and therefore, a degree of objectivity in beauty. Importantly, while the processing fluency theory is centered around the perceiver, it applies to visual artists equally as well since they actively perceive and revise their work [7]. While the aforementioned variables may have different meanings for a professional artist and a naïve viewer, the principle remains the same. Overall, the theory emphasizes that different from classical and Renaissance thinking, objectivity does not stem from elegant mathematical relations but from utilitarian evolutionary mechanisms. However, the processing fluency theory is likely to be incomplete. It does not capture the competition between different fluency variables and the resulting individuality. What leads different individuals to exist in distinct portions of the neuroaesthetic space? One reason could be external constraints, such as employer demands or availability of materials like oil versus fresco

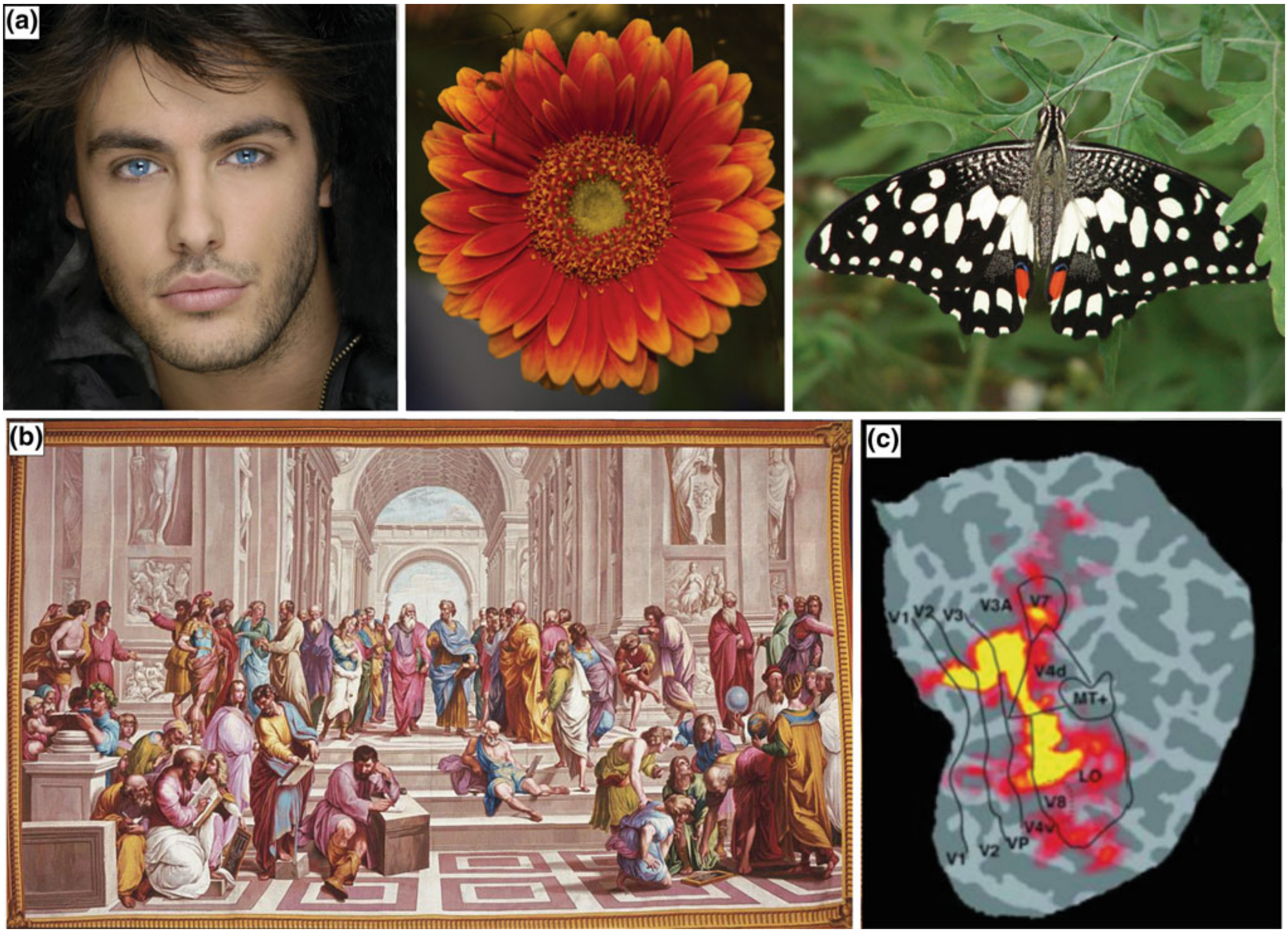


Fig. 1 Fluency of symmetry and its relation to art. **a** Symmetry is prominent in important structures in nature, such as faces [*Image Source* (https://pixabay.com/en/man-singer-musician-portrait-67467/)] plants [*Image Source* (https://pixabay.com/en/flower-flowers-summer-flowers-1431010/)], and body plans [*Image Source* (https://flic.kr/p/526sbH)]. **b** Symmetry is central in art, for example, *School of Athens* by Raphael [*Image Source* (https://library.artstor.org/asset/ARTSTOR10341822001612454)]. **c** The brain has dedicated areas devoted to symmetry (Image Reproduced with the author’s permission [26]) which allow for its fluent processing

[2]. Other reasons could be internal, such as differences in perception due to, for instance, eyesight acuity. In addition, differences could emerge in how much individuals value certain aesthetic variables. In the next section, we explore this possibility by investigating how an individual's unique learning and motivation have a role in individuality.

3 Learning and Motivation as Roots of Subjectivity in Beauty

In this section, we focus on the cognitive mechanisms underlying subjectivity in beauty. What is considered beautiful is often largely cultural. Therefore, the roots of subjectivity are likely due to differences in our environment and experience with it. How do these differences manifest in our brain? We know from other fields of neuroscience that our brains can change in both structure as well as function as a result of experience [22]. Therefore, it is not surprising that the same may happen as a result of culture. Specifically, each culture has its own unique beliefs and values and in order for us to survive, we must learn and adopt these values. Therefore, learning is fundamental for differences in subjectivity. In the brain, the learning of such cultural values may largely undergo through a mechanism known as "reinforcement learning" [30]. We will discuss the details of this process further below. Additionally, it is important to note that although populations may learn the same values, no two individuals in the same culture are exactly similar in their likes and dislikes. One reason lies in the internal states of the individual. We further discuss how reinforcement learning can be directly modulated by internal factors such as motivation or drive. Therefore, we would expect that key mechanisms in the brain giving rise to subjectivity might be related to learning and motivation.

To begin, we focus on the neural structures that most likely underlie learning of aesthetic values. We preface this discussion by emphasizing that learning of aesthetic values may not be any different than learning of values in general. Discovering the true underlying aesthetic response in the

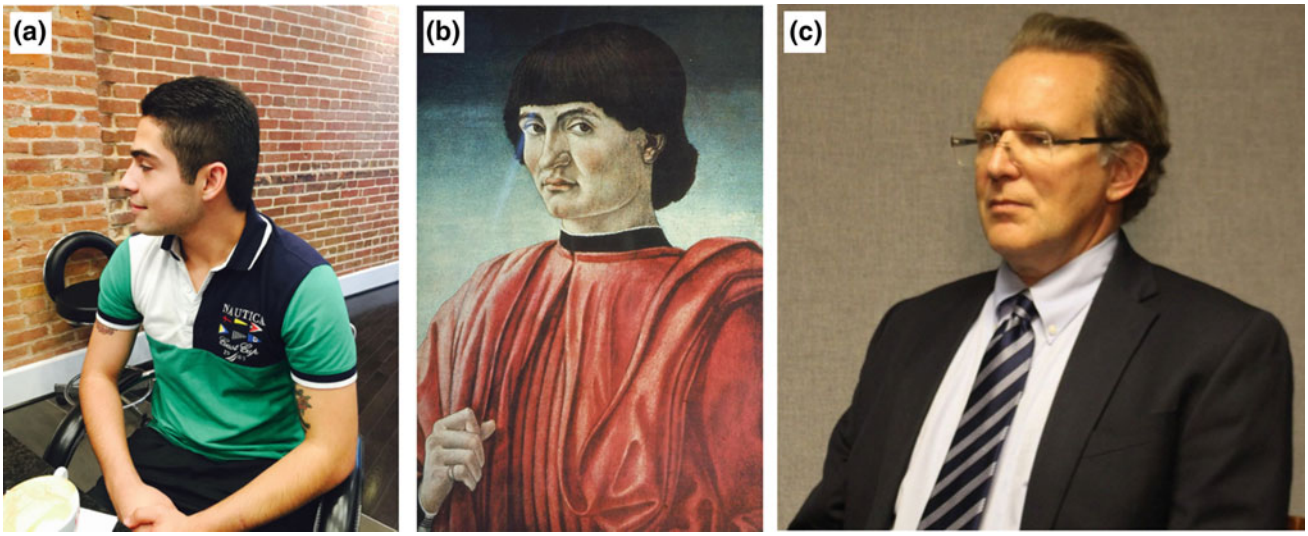
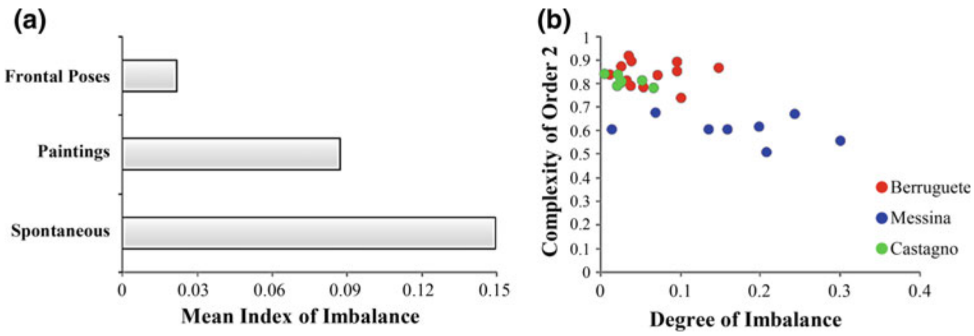


Fig. 2 Examples of images used in study of processing fluency in art **a** Spontaneously taken photograph **b** Early renaissance portrait painting, *Portrait of a Man,* by Andrea del Castagno [*Image Source* (https://www.nga.gov/collection/art-object-page.19.html)]. **c** Posed portrait photograph. *Note* All images were converted to grayscale for actual analysis

Fig. 3 Statistical analysis of early renaissance paintings. **a** Comparing balance across image categories. **b** Painters differed in their composition of complexity and balance



brain has been a challenging task for neuroscience. Part of the challenge stems from the complexity and variety of stimuli that can elicit aesthetic emotions. For example, faces, paintings, food, and music can all have their own respective aesthetic responses making it difficult to tease out what the true aesthetic response to beauty is. To tease this out, the earliest fMRI studies of beauty in art asked subjects whether they liked or disliked certain stimuli (paintings). As expected, these studies found activations in a wide array of visual areas as well as spatial, motor, emotional, and reward structures [15]. Since then, other studies have found a similar and seemingly widespread array of brain activations [8]. How can we reconcile these results? In particular, does a generalized network of brain regions that is responsible for aesthetic judgements irrespective of sensory modality exist? For example, are the brain mechanisms in "I like this painting of food" the same as in "this food is delicious"? To answer these questions, neuroscientists have used meta-analytic approaches. This approach combines the results of a range of neuroimaging studies to find the most concordant brain regions. The result of one such meta-analysis involving 93 fMRI studies of aesthetics in vision, taste, audio, and olfaction revealed a network of appraisal-related brain regions common to all sensory modalities. Specifically, the analysis found that three of the most concordant regions of activation were the orbitofrontal cortex (OFC), anterior insula, and the ventral basal ganglia [6]. This evidence suggests that aesthetic appraisal may be a special case of generalized appraisal mechanisms in the brain. We will now discuss these processes in greater detail.

The brain regions underlying appraisal are closely tied to learning of values from experience. In particular, previous research has shown the importance of these brain areas in processing and learning from rewards [6]. For example, two major functions of the OFC involve multisensory integration and tracking their sensory reward values. Similarly, the anterior insula is largely involved in interoception and assigning valence to objects concerning the motivational state of the organism. Lastly, the parts of the basal ganglia are involved in processes such as making predictions and keeping track of errors in those predictions. Combined, these areas allow the overall process of reward-based learning to occur [21]. Due to their intimate connection with sensory processing, reward, motivation, value, and learning, these regions are ideal candidates for neural circuitry underlying aesthetic learning and appraisal. A key component of this process being reinforcement learning.

To help better understand how reinforcement learning works and may be applied to aesthetics, let's look at an example. Consider the case of an individual seeing and smelling a red apple (Fig. 4a). The visual and olfactory regions would transmit pieces of sensory information to the OFC, which would integrate them into one percept. Based on this percept, parts of the basal ganglia help make a prediction about the reward gained by eating the apple, for example, "This will be sweet." Then, depending on that individual's internal motivational state, for example, "I am hungry," or "I am satisfied" as signaled for example, by the anterior insula, the person would act on the apple to test the initial prediction. Once the individual acts and eats the apple, the outcome (apple was bitter/apple was sweet) will be compared with the initial prediction. This comparison is the crux of the learning process. Here, again at the basal ganglia, the parameters of value models for the sensory inputs will be updated/learned given the reward. Thus, a certain property of apples, for example, "how red they are," is then "reinforced" and given a value. In the future, our brain can use this value as an initial guide for a prediction, allowing the individual to learn from experience and make better decisions. Similarly, the learned value will also influenced that person's preference, i.e. liking more red apples. This framework then largely encapsulates how we navigate and learn from our surroundings, and how that in turn affects our future decisions and preferences. In reality, the neural basis of these processes is much more nuanced, with much overlap. However, we have only considered those areas directly related to reward-based learning and their major roles.

From the example above, it can be seen that reinforcement learning is evolutionarily important and essential to our survival. This form of learning allows us to keep up with our ever-changing surroundings by constantly learning and updating an internal value model. Considering the fundamental nature of this process and the evidence from neuroimaging, we suggest that these same mechanisms apply when learning aesthetic values as well.

Let us now consider how this learning framework would apply when the same individual later looks at a painting of an apple (Fig. 4b). All the initial steps of the framework would be the same up to the prediction point. However, crucially, the individual cannot eat the painted apple to test the value prediction. Why may then the individual still enjoy looking at the painting? We propose that the answer lies in the previously learned "value" of the sensory aspects of the painting (for example, red equals good). This value then becomes the "aesthetic value." Just as how in processing fluency evolutionarily important features are hedonically marked, we propose a similar mechanism for aesthetic value within the reinforcement-learning framework. Thus, subjective aesthetic values may be formed in a similar manner to objective ones, albeit at a much shorter timescale. To further investigate the dynamics of exactly how these values form, we formulated a computational model based on Fig. 4.

By simulating the model, we got predictions for the dynamics of learning, individuality of aesthetic values, and cultural differences. For the purposes of this chapter, we present only an example subset of features of the model and

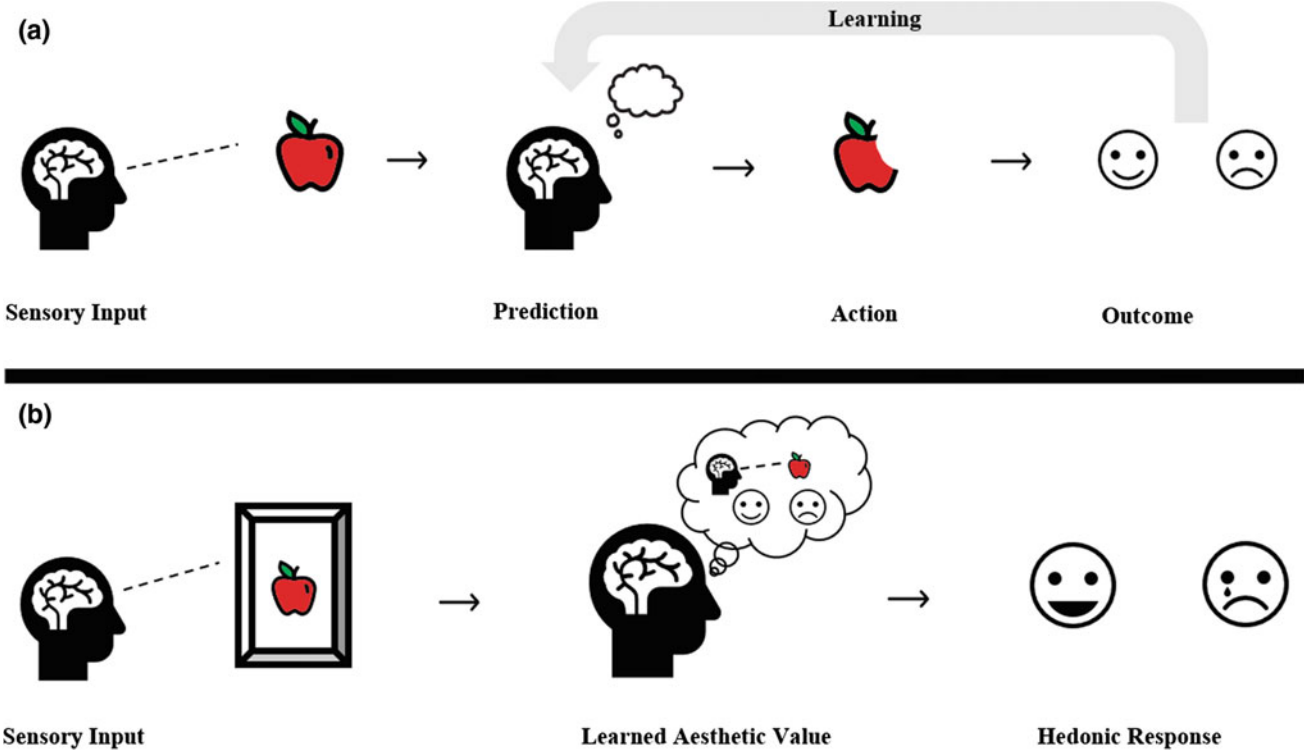


Fig. 4 Simplified illustration of reinforcement learning. **a** Case where individual encounters actual object in the environment. **b** Case where individual encounters a work of art with similar statistics to the object in the environment

in schematic form. In this example, we considered individuals who learn to weigh the aesthetic values of balance and complexity of their sensory inputs. The first feature of the learning model that we illustrate here is the motivation function (Fig. 5a). This function is the conditional probability that the individual will act given a sensory input. Thus, this function is set independently for each individual. In this example, the individual is motivated to act around certain levels of input complexity, while the motivation is independent of input balance. The second feature that we illustrate is the reward function (Fig. 5b). This function is the conditional probability that the individual will receive a “social” reward if the individual acts with the given sensory inputs. Thus, the reward function is set across all individuals of a social group. In this example, the reward increases linearly with the level of input balance. In the example of Fig. 5, we set the initial conditions of the simulations at zero, that is, the individual had no initial bias for balance and complexity.

A schematic representation of the simulated value weights for balance and complexity for an example individual appears in Fig. 5c. The weights began at zero and rose quickly. This fast rise was due to the tendency of high balance and complexity to be rewarding (see for example, Fig. 5b). However, after the rapid rise, the balance and complexity weights began to diverge. The latter went up slowly, while the former went down. Consequently, although balance and complexity had positive aesthetic values, this divergence phase indicated their inter-competition as described in the introduction to Fig. 3b. This competition phase lasted a relatively long time, eventually converging to a steady state. These results suggest an intriguing hypothesis for how we may learn aesthetic values. For example, the bulk of learning may be witnessed either early in development or when there is a dramatic change in environment, such as moving to a foreign country. Many questions about the timescale dynamics of aesthetic learning remain. We are currently performing behavioral experiments to shed more light on this issue.

Next, we investigated how aesthetic preferences would vary for individuals undergoing learning under different motivation functions. In our example, we considered two different individuals with preference for lower and higher levels of complexity (left panel of Fig. 5d). We informally thought of them as risk-averse and risk-taker individuals respectively. The results suggested that difference in risk-taking could lead to drastically different endpoints in aesthetic value (middle panel of Fig. 5d). For the risk-taker, the complexity and balance weights tended to be high and low respectively at steady state. However, for the risk-averse

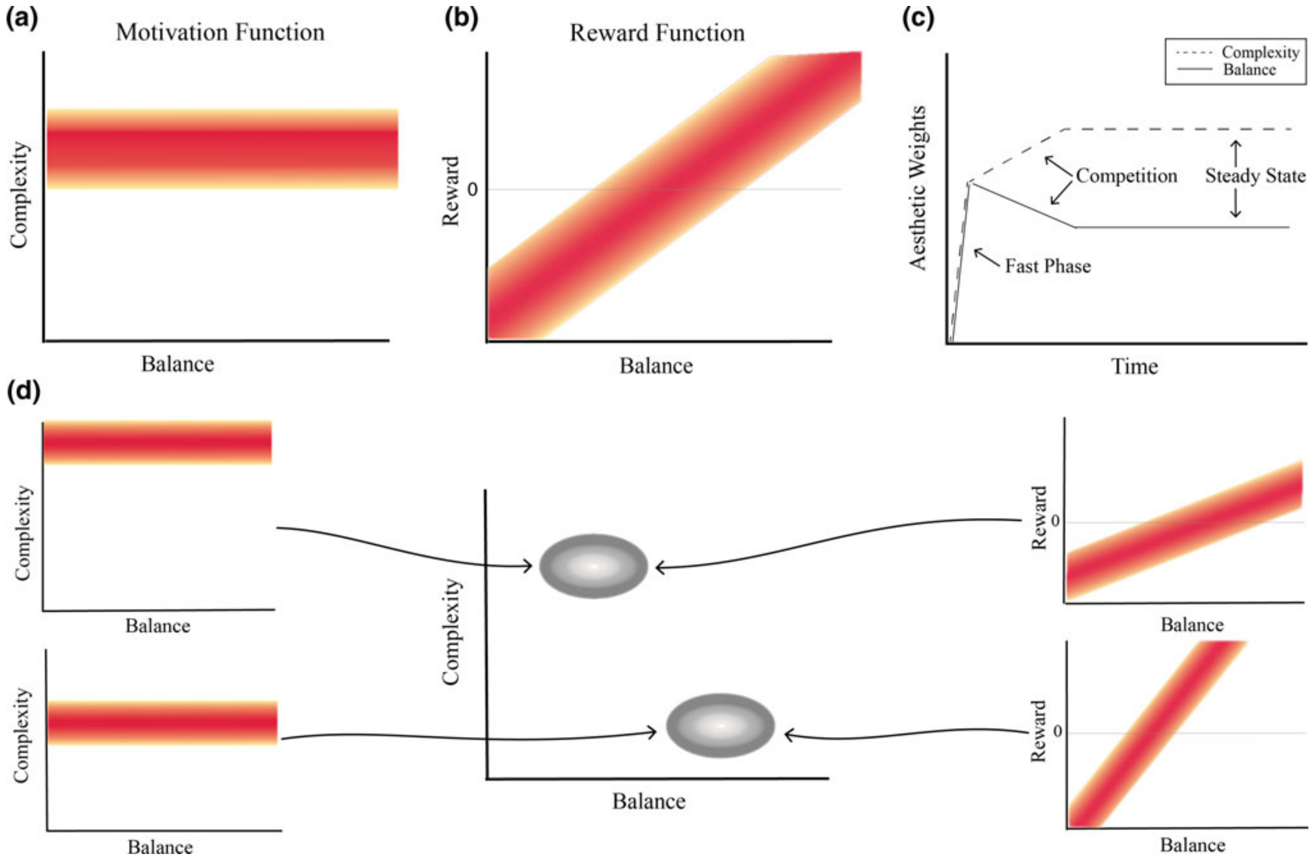


Fig. 5 Schematic overview of some features of the model and its predictions. **a** The conditional probability distribution of motivation given complexity and balance. **b** The conditional probability distribution of reward given balance. **c** An illustration of the dynamics of how the aesthetic weights of balance and complexity are updated. **d** An illustration of how changes in motivational state or social reward affect learning of aesthetic values. The left panel shows examples of two different motivation functions as in A. The right panel shows examples of two different reward functions as in B. The center panel illustrates the distribution of aesthetic weights at steady state (see Panel C) because of changes in motivation and reward functions

individual, the opposite happened. These results suggested that difference in motivation during learning are a factor underlying aesthetic individuality (see the end of Sect. 2 for more factors). In terms of real-world implications, there is convincing behavioral evidence for personality traits being a determining factor in aesthetic preferences. These studies are consistent with our results that show greater preference for complexity with more risk-taking personality traits [10]. Our results can therefore serve as a possible computational basis for these findings.

Lastly, we also investigated how changes in social reward functions could give rise to distinct aesthetic preferences. In our example, we performed simulations with different reward functions. To do this, we varied the slopes of the balance reward function. The results in Fig. 5d again show that just like internal motivational states, external factors such as social rewards can also result in individuals ending up with distinctly different aesthetic values. In particular, the results showed that when the balance reward function had steeper slopes, the complexity and balance weights tended to be low and high respectively at the steady state. However, for shallower slopes of the balance reward function, the opposite happened. Hence, different cultures with distinct reward functions could lead to divergence of aesthetic values. This finding is consistent with previously discussed evidence for the cultural dependence of aesthetics.

Overall, the results from our computational model suggest some possible mechanisms for how aesthetic subjectivity arises. Hence, subjectivity can arise from a multitude of factors, ranging from external differences such as culture, to internal differences such as motivation and learning dynamics. How each one of us arrives at our respective preferences may then be a unique function of the interaction of these two dynamics.

4 Discussion

Our search for the neuroscientific basis of objectivity and subjectivity in beauty ended up revealing something unexpected to us: both are reflections of utilitarian brain mechanisms. Beauty may not be the direct result of objective mathematical properties as once thought by Plato or Renaissance thinkers. Instead, objectivity may have arisen in part to our evolutionary history and principles captured by the processing fluency theory. Here, it is important to note that our definition of objectivity may differ with that of philosophy. Instead of objectivity being purely a priori qualities of the world, we extend it to mean the universality of response in human observers. For example, symmetry may be universally preferred because of its fluent processing as a result of shared dedicated neural circuitry [31]. Similarly, brain circuitry evolved for survival, particularly reward-based learning, may have given rise to subjectivity in beauty. Neuroimaging studies suggest that aesthetic appraisal depends in part on reinforcement-learning and motivational state circuitries in the brain [6]. We extend this framework in a computational model to show how it could be a basis for subjectivity. Additionally, we emphasize the role of the individual in aesthetic learning. While learning is central for social and environmental adaptability, individual motivational states help us choose actions that are best for ourselves. Thus, learning under the constraints of motivational states could give rise to subjective individual experiences of beauty. Lastly, we stress the "naturalistic" viewpoint of aesthetics [6, 28]. We propose that same evolutionary, learning, and motivational mechanisms that are involved in the appraisal of values in everyday decisions are also involved in aesthetic appreciation. It is possible then that same generalized value-computing brain circuitries may be "co-opted" for the appraisal of beauty as well. More specifically, we propose that the estimated value is akin to aesthetic value.

Taken together with evidence from neuroimaging studies, our results suggest that the processes underlying objective and subjective aesthetics are no different from the mechanisms of appraisal. Therefore, our hypotheses imply that both objective and subjective aspects of beauty lie within the perceiver's brain. This contrasts with the early philosophical perspectives that subjectivity is internal, while objectivity is external. We argue that this is not the case, that is, both are internal, with objective beauty also depending on underlying brain mechanisms. Thus, objectivity and subjectivity may represent two different ways of building values. Objectivity may be at the scale of evolution, thus more rigid and universal. In contrast, subjectivity may be at the scale of reinforcement learning, being more flexible and individualized. In turn, the interaction of these two mechanisms can account for both the universality as well as the individuality in human preferences across the globe. While all of us may be born with similar aesthetic biases, over time these biases are shaped by our experience through learning.

What are the implications for neuroscientists, artists, or anyone who appreciates beauty given our assertion that both objectivity and subjectivity may be internal to the brain? That beauty may manifest from the same fundamental evolutionary mechanisms as learning and survival should not diminish its importance. At the same time, maintaining an esoteric viewpoint of beauty will not further its understanding. The field of neuroaesthetics could benefit greatly by investigating aesthetic phenomena in the context of other fundamental brain processes such as memory and emotion. As for artists, knowing the neuroscientific basis of aesthetics may allow them to better understand the reasoning behind their academic principles, as well as allowing them to innovate and improve their art. For example, better understanding the interplay between internal and external dynamics of the viewer's brain may allow artists to create a better, more individualized museum experience [16]. While we are far away from uncovering the true nature of beauty and aesthetic appreciation, we must persist with knowing that the knowledge gained can improve our understanding both in the lab as well as in the studio.

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