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AESTHETIC SENSITIVITY

Ana Clemente Sánchez

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Doctoral Program: Human Evolution and Cognition

AESTHETIC SENSITIVITY

Ana Clemente Sánchez

Director/Supervisor: Marcos Nadal

Doctor by the University of the Balearic Islands

Compendium of Publications

Clemente, A. (in press). Aesthetic Sensitivity: Origin and Development of an Idea. In Nadal, M. & Skov, M. (Eds.), *The Routledge International Handbook of Neuroaesthetics.*

Clemente, A., Pearce, M. T., & Nadal, M. (2021). Musical aesthetic sensitivity. *Psychology of Aesthetics, Creativity, and the Arts*. Advance online publication. https://doi.org/10.1037/aca0000381

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Corradi, G., Chuquichambi, E. G., Barrada, J. R., **Clemente, A.**, & Nadal, M. (2020). A new conception of visual aesthetic sensitivity. *British Journal of Psychology, 111*(4), 630–658. https://doi.org/10.1111/bjop.12427 (JCR$_{2019}$ Impact factor: 3.239)

Nadal, M., Corradi, G., Barrada, J. R., **Clemente, A.**, & Chuquichambi, E. G. (2020). Reply to Myszkowski et al. (2020): Some matters of fact concerning aesthetic sensitivity. *British Journal of Psychology, 111*(4), 663–664. https://doi.org/10.1111/bjop.12443 (JCR$_{2019}$ Impact factor: 3.239)

Universitat
de les Illes Balears

Dr. Marcos Nadal, Universitat de les Illes Balears,

I DECLARE:

That the thesis titled **Aesthetic Sensitivity**, presented by **Ana Clemente Sánchez** to obtain a doctoral degree, has been completed under my supervision and meets the requirements to opt for an International Doctorate.

For all intents and purposes, I hereby sign this document.

Signature: Marcos Nadal

Palma de Mallorca, April 30, 2021

Acknowledgments

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I dedicate this work to victims of inequality and to lovers of art and science.

Index

Abstract

Aesthetic sensitivity is a central idea in the field of empirical aesthetics. The present research contributes a historical-critical review of its origin and development through the history of the discipline, a new theoretical approach aligned with current knowledge, novel methodological tools to investigate this and other relevant psychological constructs, and empirical evidence based on this conception that advances scientific understanding of sensory valuation.

La sensibilidad estética es una idea central en el campo de la estética empírica. La presente investigación aporta una revisión histórico-crítica de su origen y desarrollo a través de la historia de la disciplina, un nuevo enfoque teórico de acuerdo con los conocimientos actuales, novedosas herramientas metodológicas para investigar éste y otros constructos psicológicos relevantes, y evidencia empírica basada en esta concepción que avanza la comprensión científica de la valoración sensorial.

La sensibilitat estètica és una idea central en el camp de l'estètica empírica. La present investigació aporta una revisió històric-crítica del seu origen i desenvolupament a través de la història de la disciplina, un nou enfocament teòric alineat amb els coneixements actuals, noves eines metodològiques per investigar aquest i altres constructes psicològics rellevants, i evidència empírica basada en aquesta concepció que avança la comprensió científica de la valoració sensorial.

I

Introduction

Introduction

To be consistent, relevant, and advancing, any scientific field must regularly revise and reconsider its objects of study and the assumptions it relies on (Nadal, 2020). This implies that we, scientists, should be aware of and question the origin and validity of the concepts and methodology on which our work relies, their principles, functions in science and society, and usefulness to contribute knowledge. Of course, this entails acting in consequence: including revision tasks in the scientific agenda, being open to preserving or discarding notions and methods, and seeking better alternatives accordingly. This policy will not only strengthen the foundations and relevance of a particular discipline but foster fertile intra- and inter-disciplinary discussion and promote the generation of new research tools, paradigms, evidence, and, ultimately, knowledge.

The present research is motivated by, and fruit from, an exercise of such self-discipline. Its contributions to science are, thus, historical (chapter III), theoretical (chapters V and VI), methodological (chapter VII), and empirical (chapters V, VIII, and IX), setting a platform for a more sophisticated investigation of the nature of sensory valuation in future research. Such contributions take the form of published journal articles and a book chapter in press. This doctoral dissertation is therefore presented as a compact compendium of publications constituting a well-defined research line.

This dissertation is structured as an argument: After presenting the general and specific objectives of this research (II), two introductory chapters (III and IV) expound the conceptual and neuroscientific framework. The central chapters (V to IX) correspond to the published papers and constitute the core of this dissertation. The dissertation concludes with a general discussion (chapter X) and conclusions (chapter XI). Below, I summarize the purpose of each chapter emphasizing the logic and coherence of the scientific argument.

II. Objectives threads the thesis' overarching goal—introducing and applying a new conception of aesthetic sensitivity in the service of understanding sensory valuation—through each of the studies that represent its main body.

III. Aesthetic Sensitivity: Origin and Development of an Idea (Clemente, in press) argues that aesthetic sensitivity is a central albeit polymorphic idea in empirical aesthetics, as it has been defined and operationalized in multiple ways through the history of the discipline. This chapter presents a critical review of the emergence and evolution of the main notions of aesthetic sensitivity, discussing their roots, relevance, and function. Therefore, it motivates, contextualizes, and provides historical depth to our new conception of aesthetic sensitivity.

IV. Aesthetic Sensitivity in Sensory Valuation situates our notion and measure of aesthetic sensitivity within the neurobiological and psychological investigation of sensory valuation. Whereas traditional notions of aesthetic sensitivity are rooted in dated beliefs, the conception put forward in this thesis is aligned with current psychological and neuroscientific knowledge. Specifically, it was devised as a means to investigate sensory valuation. This chapter succinctly provides the neuroscientific background to understand and put into perspective the theoretical, methodological, and empirical contributions detailed in subsequent chapters.

V. A New Conception of Visual Aesthetic Sensitivity (Corradi, Chuquichambi, Barrada, Clemente, & Nadal, 2020) introduces and discusses our new conception of aesthetic sensitivity. We define aesthetic sensitivity as the extent to which variation in a specific stimulus property influences someone's appreciation. In other words, it is the degree to which the evaluative judgment of an object by an individual relies on a particular object feature. Consequently, we measure it as the individual variability in hedonic value regarding variation in a particular feature, which we compute as the individual slope in linear mixed-effects models. The studies included in this dissertation focus on *liking* and on four stimulus features whose influence on appreciation is well-established in the literature on visual aesthetics: balance, contour, symmetry, and complexity. To test our notion and measure of aesthetic sensitivity in the visual modality, this chapter examines aesthetic sensitivity in terms of individual variability in liking ratings to visual designs varying in these properties, and investigate its general or multiple nature, temporal stability, and associations to other traits typically affecting appreciation.

VI. Reply to Myszkowski et al. (2020): Some Matters of Fact Concerning Aesthetic Sensitivity (Nadal, Corradi, Barrada, Clemente, & Chuquichambi, 2020) is our response to Myszkowski, Celik, and Storme's (2020) commentary to our new approach to aesthetic sensitivity, a sign of the debate it aroused in the scientific community.

VII. A Set of 200 Musical Stimuli Varying in Balance, Contour, Symmetry, and Complexity: Behavioral and Computational Assessments (Clemente et al., 2020) is the first step toward applying our new notion of aesthetic sensitivity from the visual to the auditory modality. To that end, I composed the MUST, a set of musical motifs emulating variation in the stimulus sets used in Corradi et al.'s (2020) study. They were expressly designed for empirical research, combining experimental control and musical appeal. Then, we assessed the stimuli behaviorally and computationally, devising computational measures (the MUST toolbox) for the structural parameters manipulated and deriving composite measures of perceived musical balance, melodic and rhythmic contour, musical symmetry, and melodic and rhythmic complexity, respectively. This chapter offers a complete description of the stimulus design, assessments, and computational measures. The MUST set and toolbox are publicly available at https://osf.io/bfxz7/.

VIII. Musical Aesthetic Sensitivity (Clemente, Pearce, & Nadal, 2021) uses the materials above to study our notion and measure of aesthetic sensitivity in the auditory modality. This chapter ascertains whether the individual variability, multiplicity, and temporal stability of aesthetic sensitivities are comparable across sensory modalities, whether musical aesthetic sensitivities combine in any particular way, and their relationships with other individual traits.

IX. Evaluative Judgment Across Domains: Liking Balance, Curvature, Symmetry and Complexity in Musical Motifs and Visual Designs (Clemente, Pearce, Skov, & Nadal, 2021) examines aesthetic sensitivities across the visual and auditory modalities. Namely, it elucidates the modality-specific or modality-general nature of sensory valuation by asking the same cohort to rate their liking for the visual and musical stimuli in previous studies.

X. Discussion brings together the findings in the studies above and analyzes their implications. In this chapter, I revise the validity and functionality of our conception of aesthetic sensitivity and the value and impact of the publications included in this dissertation. Further, I advance related ongoing and projected research and reflect on the limitations and prospects of our approach, posing central questions and suggesting ideas for further investigation.

XI. Conclusions wraps up this doctoral dissertation with some general and final remarks.

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Clemente, A. (in press). Aesthetic Sensitivity: Origin and Development of an Idea. In Skov, M. & Nadal, M. (Eds.), *The Routledge International Handbook of Neuroaesthetics.*

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II

Objectives

Objectives

The primary aim of this doctoral thesis is to advance our scientific understanding of sensory valuation through a new conception of aesthetic sensitivity. This overarching goal comes to fruition through several specific objectives that motivated and defined the studies in this and other ongoing and planned projects. This chapter explains the specific objectives of this doctoral research, elaborating on their rationale and realization.

Theoretical Objectives

Science's overhaul duties mentioned in the Introduction entail integral revisions of the core concepts of every discipline. Such a revision involves inquiring into the origin, meaning, and function of each of those concepts. A first sensible step is, thus, reviewing the literature on the concept from a broad perspective, considering the evolving context in which it emerges and develops, because its meaning and function are inextricably bound to a specific space and time. This is precisely the logic behind **Aesthetic Sensitivity: Origin and Development of an Idea** (Clemente, in press, chapter III). Thus, the first objective is to contribute a critical historical review of aesthetic sensitivity.

This project was motivated not only by the observation of contradictory and problematic conceptualizations, operationalizations, evidence, and uses of aesthetic sensitivity in the literature, but by more practical questions: What is the current usefulness of traditional conceptions of aesthetic sensitivity? Are they meaningful and useful in our field now? What are their actual implications? An ultimate goal in the field is to understand appreciation, but this research revealed that traditional notions seem to be much more harmful than useful in this regard. They rest upon unsupported assumptions and do not contribute to understanding individual differences in appreciation, which is crucial to understand the process of appreciation itself. In contrast, individual variability does. Specifically, the extent to which differences in degree of a stimulus feature lead to differences in individual appreciation shows a huge potential as a means to investigate appreciation. However, it has never been investigated before. Such a construct perfectly matches the term *aesthetic sensitivity*.

The theoretical objectives are, therefore, to argue in favor of discarding the traditional notions of aesthetic sensitivity, and to introduce a new conception in line with current knowledge and useful to understand psychological phenomena. Both objectives are put forward in **A New Conception of Visual Aesthetic Sensitivity** (Corradi, Chuquichambi, Barrada, Clemente, & Nadal., 2020, chapter V), complemented in **Musical Aesthetic Sensitivity** (Clemente, Pearce, & Nadal, 2021, chapter VIII) and **Reply to Myszkowski et al. (2020): Some Matters of Fact Concerning Aesthetic Sensitivity** (Nadal, Corradi, Barrada, Clemente, & Chuquichambi, 2020, chapter VI), and completed in **Aesthetic Sensitivity: Origin and Development of an Idea** (Clemente, in press, chapter III).

Methodological Objectives

Scientific understanding involves testing hypotheses and contributing empirical evidence. Our notion and measure were conceived as means to advance the scientific understanding of sensory valuation. Devising and testing them constituted a primary methodological objective, achieved in **A New Conception of Visual Aesthetic Sensitivity** (Corradi et al., 2020, chapter V). To probe them in the music domain required the creation of a stimulus set and computational measures, which represents another methodological objective accomplished in **A Set of 200 Musical Stimuli Varying in Balance, Contour, Symmetry, and Complexity: Behavioral and Computational Assessments** (Clemente et al., 2020, chapter VII).

Empirical Objectives

The primary goal of this doctoral research involves an eminently empirical investigation. The studies included in this dissertation address several empirical objectives summarized below and directed to understand sensory valuation:

1. To ascertain whether aesthetic sensitivity is single or multiple and universal or individual in nature.
2. To determine the reliability of aesthetic sensitivities, i.e., their temporal stability.
3. To explore how aesthetic sensitivity relates to other individual differences.
4. To elucidate whether people converge into any pattern of aesthetic sensitivities.
5. To clarify whether sensory valuation relies on modality-specific sensory representations or abstract modality-general representations.

Objectives 1 to 3 were addressed in **A New Conception of Visual Aesthetic Sensitivity** (V; Corradi et al., 2020) and **Musical Aesthetic Sensitivity** (VIII; Clemente et al., 2021). The latter also involved objective 4. Finally, **Evaluative Judgment Across Domains: Liking Balance, Curvature, Symmetry and Complexity in Musical Motifs and Visual Designs** (IX; Clemente, Pearce, Skov, & Nadal, 2021) tackled objective 5 and added to objective 3.

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III

Aesthetic Sensitivity:

Origin and Development of an Idea

Aesthetic Sensitivity: Origin and Development of an Idea

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Aesthetic sensitivity is a core idea in empirical aesthetics, referred to the appreciation of sensory objects. Throughout the history of the discipline, it has been conceptualized in many ways. Two antagonistic notions of aesthetic sensitivity encompass most contributions in the literature: On one side, the promoters of a *normative* notion—comprising *determinist* and *educative* views—devised it for educational purposes. On the other, the advocates of sensitivity as *responsiveness* to sensory stimulation—as *sensitivity* is commonly understood and defined—conceived it as a means to investigate sensory valuation. This chapter critically reviews each notion's emergence and development through its leading proponents, considering their influences, context, and scientific impact.

Keywords: aesthetic sensitivity, ability, hedonic value, intelligence, responsiveness, sensory valuation, taste

De gustibus non disputandum est—Roman dictum

1. Introduction

Aesthetic sensitivity is a central, polymorphic idea in empirical aesthetics, intrinsically linked to that of *aesthetic experience*. As Tomlin (2008) observed for the disparity of definitions of aesthetic experience, it has been conceptualized in multiple ways throughout the history of the discipline. All refer, however, to the appreciation of sensory objects. The multiple perspectives and attitudes on aesthetic appreciation and its functional value gravitate to two antagonistic notions of aesthetic sensitivity, encompassing most contributions in the literature: On one side, the promoters of a *normative* notion—comprising a *determinist* and an *educative* view—devised it originally for educational purposes. On the other, the advocates of sensitivity as *responsiveness* to sensory stimulation conceived it as a means to investigate sensory valuation. Such divergences are in some cases radical, blurred or intertwined in others, or show a sort of evolution in line with their scientific, philosophical, and sociopolitical context. These categories are, thus, proposed as a means to articulate a historical approach to aesthetic sensitivity. Nevertheless, these differences have granted *aesthetic sensitivity* or *taste* considerable research attention and, rather than following the aphorism above, being an object of hot scientific debate—e.g., between Eysenck and Child, or between Myszkowski and Nadal.

This chapter investigates the origin and development of each notion of aesthetic sensitivity through its leading proponents, considering their influences, context, interests, and scientific impact. For conciseness, it focuses on the emergence and evolution of aesthetic sensitivity since the advent of psychology and restricts to English literature mostly in empirical aesthetics, given its prevalent influence on current approaches. Thus, the chapter's intended character is more of a discussion, including a critical but not comprehensive literature review, for it pursues an analysis of the principal conceptions of aesthetic sensitivity, not all their uses and manifestations. The chapter is structured around the main trends observed in the literature: **Section 2** deals with the terminology used throughout the history of the discipline. **Section 3** presents an overview of the authors' intellectual lineages to understand the scientific influences affecting their premises, attitudes, and interests. **Section 4** contextualizes the origin of aesthetic sensitivity notions in the field. **Sections 5** and **6** focus on each main view through their chief figures' constructs and findings. Lastly, the chapter concludes with a brief discussion and remarks in **section 7**.

2. Terminology

Aesthetic sensitivity is a polymorphic idea denoted by a complex nomenclature: The same expression has been attributed multiple meanings, and various terms have been used as synonyms for the same construct. We owe the first appearance of *aesthetic sensitivity* in empirical aesthetics literature to Meier (1928). However, the idea is rooted in 18th-century Aesthetics and finds a direct precursor in *aesthetic taste* (section 4). According to Google Ngram Viewer (Michel et al., 2011), *aesthetic taste* has a long and prolific history, and its use started to decline along with the emergence of *aesthetic sensitivity* (Figure 1). The diverse forms with which it is referred to in the literature (*aesthetic*/*esthetic sensitivity*/*sensitiveness*) reflect diverse traditions and linguistic variants. Among them, *aesthetic sensitivity* became the prevalent form at the beginning of the 20th century (Figure 2), so it is used in the chapter to allude indistinctly to any variant. Likewise, the idea of aesthetic sensitivity appears also under designations like *taste*, *aesthetic judgment*, or *preference*, which are consequently discussed.

Figures 1 and 2 illustrate the notion's emergence around 1850, its development over the first half of the 20th century, its momentum gain over the third quarter of the century to reach its heyday between 1960 and 1980—even if compared to psychological literature in general (Figure 3)—, and its subsequent decline. Notably, the height coincides with the most active and prolific stages of the leading proponents of the traditional views (section 5), a proliferation of art research using scientific methods—particularly statistics and tests (Chalmers, 1977)—, and a prime interest in educating aesthetic sensitivity (Kertz–Welzel, 2005).

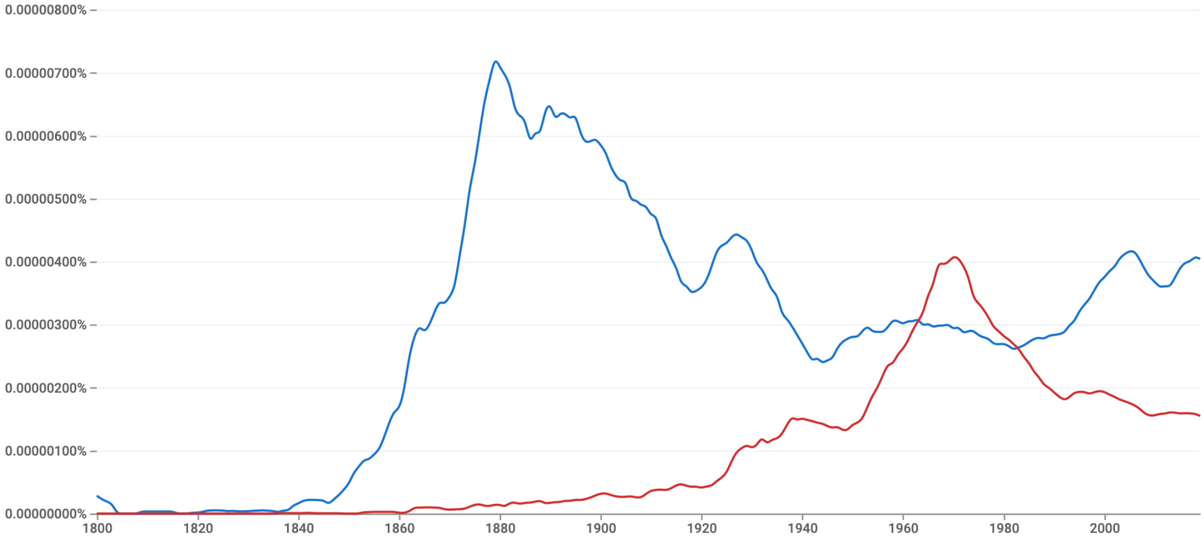

Figure 1. Frequency of books mentioning *aesthetic taste* (blue) and various forms of *aesthetic sensitivity* (i.e., *aesthetic*/*esthetic sensitivity*/*sensitiveness*) combined (red) in English between 1800 and 2019. Source: Google Ngram Viewer (Michel et al., 2011).

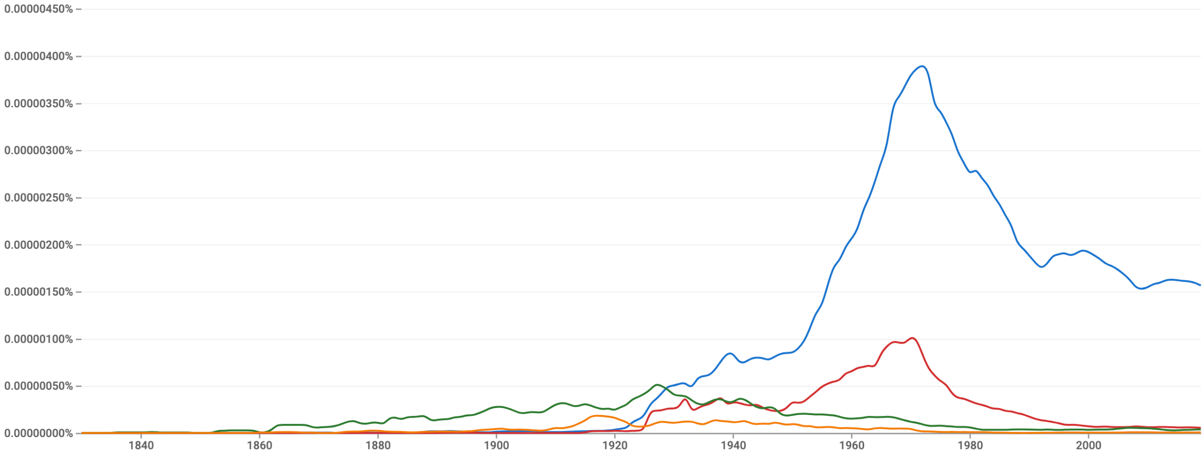

Figure 2. Frequency of books mentioning *aesthetic sensitivity* (blue), *esthetic sensitivity* (red), *aesthetic sensitiveness* (green), and *esthetic sensitiveness* (yellow) from 1800 to 2019. Source: Google Ngram Viewer (Michel et al., 2011).

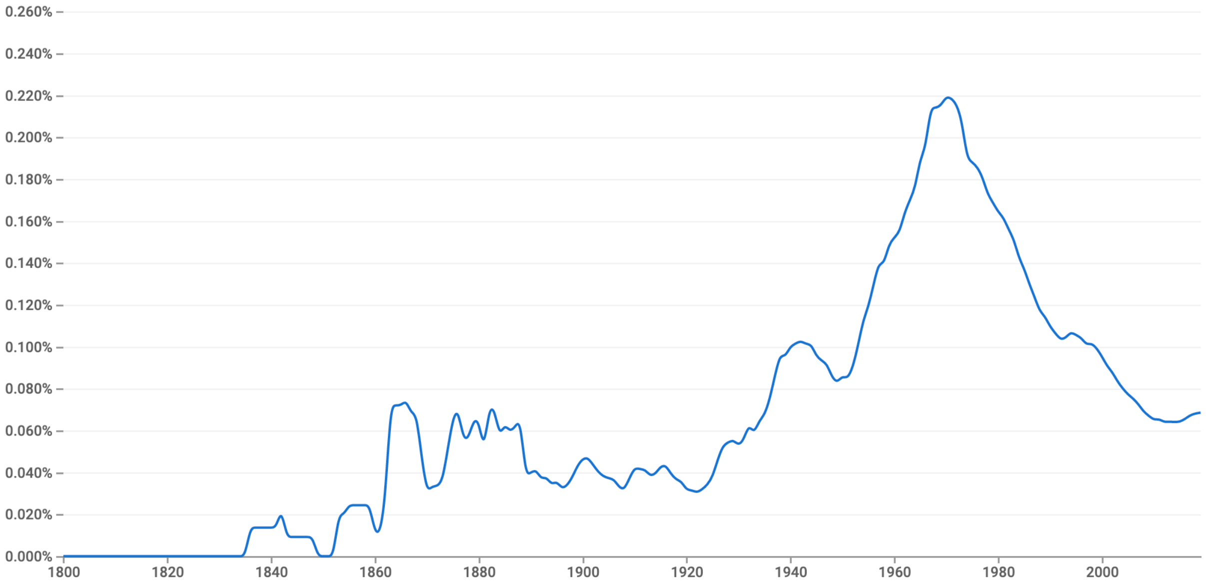

Figure 3. Combined frequency of books containing *aesthetic sensitivity*, *esthetic sensitivity*, *aesthetic sensitiveness*, and *esthetic sensitiveness* divided by the total frequency of books containing *psychology* dating 1800–2019. Source: Google Ngram Viewer (Michel et al., 2011).

3. Historical Panorama of Aesthetic Sensitivity in Empirical Aesthetics

An overview of the leading figures contributing to aesthetic sensitivity and their academic lineages may help contextualize each trend within the discipline and understand the scientific influences affecting their premises, attitudes, and interests. Figure 1 illustrates the academic genealogy of each conception of aesthetic sensitivity. Two main approaches to appreciation can be distinguished in the literature: Traditional notions are normative, as they identify sensitivity with the ability to detect, prefer, or appreciate objective aesthetic value, and include a *determinist* view and an *educative* view. Unlike them, Nadal and colleagues' conception of aesthetic sensitivity constitutes the only notion of aesthetic sensitivity based on *responsiveness* to sensory stimuli.

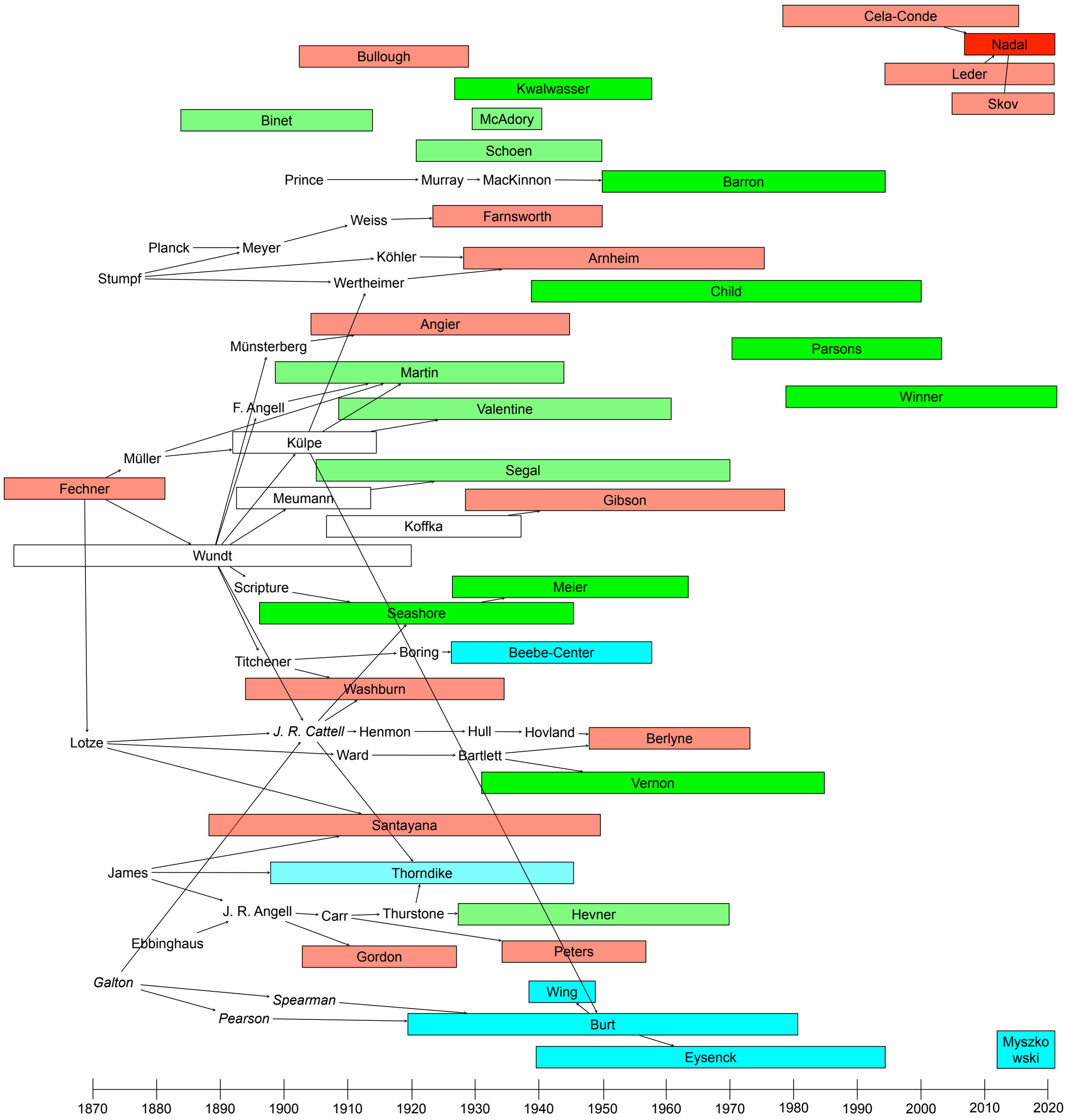

Figure 4. Academic genealogy of contributors to the literature on aesthetic sensitivity or taste in empirical aesthetics. Boxes are placed chronologically and cover approximate productive periods. Frames highlight prominent figures in empirical aesthetics. Saturated-color boxes indicate direct contributors to aesthetic sensitivity in the field. Light-color boxes indicate indirect contributors to aesthetic sensitivity. Blue tones represent the *determinist* view. Green tones represent the *educative* view. Red tones represent the *responsiveness* notion. Solid arrows indicate known influences such as teacher–student or mentor–mentoree. Lines (not arrows) denote relevant collaborations.

Some aspects are worth noting here: First, as the founder of empirical aesthetics, Fechner constitutes a stem figure, to which most researchers in the field trace back their influences (Nadal & Ureña, 2021). The *responsiveness* notion echoes back some of his pioneering thoughts, although they coexist with radically different perspectives. Indeed, even if unique, the *responsiveness* notion of aesthetic sensitivity converges in many respects with relevant contributions to empirical aesthetics. This highlights the need for historical perspective, at least within a discipline, to maximize research efficiency and consistency. Also critical is the fact that few researchers devoted their careers exclusively to empirical aesthetics, which granted a multiplicity of interdisciplinary influences. Fechner himself had a medical background and profound philosophical concerns, and conceived empirical aesthetics as applied psychophysics (Murphy, 1929) to understand the quantitative relationship between stimulation and sensation (Nadal & Ureña, 2021; Clemente, Pearce, & Nadal, 2021). Similarly, trends and ideas in psychology influenced conceptions and functions of aesthetic sensitivity throughout its history. To begin with, educational psychologists at the turn of the 20th century devised aesthetic sensitivity for educational purposes. This is also the case of intelligence, a central construct in psychology to which early proponents conceived aesthetic sensitivity to be tied.

4. Early Empirical Aesthetics

The concept of aesthetic sensitivity is intrinsically linked to that of *aesthetic experience*. Therefore, the origin and development of the former should be found in the emergence and evolution of the latter, which existed before psychology and modern neuroscience. The concept of aesthetic experience was forged out of interests unrelated to any scientific understanding of the human brain, cognition, or behavior. Instead, it emerged during the 18th century in Europe from social transformations that privileged art and the wealthy, the philosophical discourse of the truth of judgments, and the appropriation of how such judgments ought to be (i.e., *disinterested*) to characterize how experiences are, to promote that art has no value beyond itself: the *art for art's sake* (Nadal, 2020; Skov & Nadal, 2020b). In this scenario, *taste*—meaning the proper way to appreciate art—was an important sign of social standing (Shiner, 2001).

With the advent of psychology in the 19th century, aesthetic experience entered the psychological discourse. As one of the delusions that language inflicts on the mind (James, 1890), the concept of aesthetic experience was never devised to denote substantive psychological entities but resulted from a long and convoluted history of sociocultural and ideological transformations (Nadal, 2020). However, the above ideas filtered into psychology and neuroscience and crystalized as tacit assumptions (Skov & Nadal, 2020b). Consequently, as they did with many inherited philosophical concepts, psychologists treated aesthetic experience as if it defined the boundaries of a psychologically and neurobiologically meaningful class of experiences, futilely seeking to identify their psychological essence (Nadal, 2020).

Aesthetic experiences were assumed to involve special aesthetic emotions and no physiological changes (James, 1890), be elicited by specific objects (Bain, 1883; Sully, 1892), and lack social or adaptive function (Ribot, 1897; Sully, 1892). That they lacked some essential features of emotions was key to justifying their *specialness*, a topic in 20th century psychological literature—e.g., as the object of art (Lund & Anastasi, 1928), involving a special attentive state, centered on beautiful objects (Hevner, 1937), and entailing pleasure and disinterestedness (Valentine, 1913a): "For the appreciation of beauty the (spectator's) personal and practical interest must cease" (Myers, 1937, p. 75). On this ground, the emerging field largely consecrated itself to provide scientific evidence to support these beliefs or based psychological research on them.

Of particular relevance for the ideas of aesthetic sensitivity and aesthetic experience was the consideration of the factors affecting aesthetic appreciation and the treatment of individual differences with regard to them. Early research in empirical aesthetics unveiled several factors driving aesthetic appreciation. From his experiments and observations, Fechner (1876) concluded that liking resulted from the interaction of a *direct* factor—the pleasingness produced by object features and arrangements—and an *associative* factor—knowledge, memories, and past experiences when appraising the object. Thus, liking was not an automatic response to object properties but fruit of their meaning and value to each individual, depending on previous knowledge and experience (Nadal & Ureña, 2021). In this line, Segal's figures evoked a broad range of feelings and thoughts (Segal, 1906), which he considered to be the source of pleasingness (Segal, 1905, 1907), and whose main determinants were personality, moods, and dispositions—which he called *pre-aesthetic* factors, common to all kinds of experiences (Segal, 1905, 1906). Bullough (1908, 1910) found perceptive *types* in the aesthetic appreciation of colors: Whereas some people relied on object properties, others based their judgments on the associations elicited.

Subsequent approaches incorporated value judgments of appreciation and the idea of aesthetic sensitivity: Valentine (1919) found a bipolar factor suggesting that the type of aesthetic appreciation accounted for the individual's level of aesthetic development, quantifiable by the use of *higher* or *lower* judgments. According to Beebe-Center (1932), the pleasantness or unpleasantness experienced from an object was a function of the object properties—explaining a certain degree of agreement—, and contextual and personal factors —responsible for a certain degree of disagreement among people and within people at different times. He applied statistical techniques that enabled isolating a general factor of intelligence to measure general hedonic value (Beebe-Center, 1929) and individual conformity to such a consensus, defining *aesthetic sensitivity* as a function of the correlation between individual and consensual rankings of hedonic values (Beebe-Center, 1932).

Two divergent considerations of individual differences in aesthetic appreciation and their underlying factors may find their origin in these studies: On one side, some experimental psychologists treated objective and subjective factors as constituents of aesthetic appreciation, intertwined and with different relevance for different people. On the other, whereas subjective factors accounted for individual differences, objective factors underlay a common foundation of aesthetic appreciation. This duality of perspectives was essential to subsequent conceptions of aesthetic sensitivity: The former focused on the subject and ultimately crystallized in the *responsiveness* notion, genuinely interested in understanding individual differences. The latter derived into the *normative* views of aesthetic sensitivity as ability, taking object properties as the core determinants of taste, and individual differences as deviations from a norm.

5. The Normative Tradition: Aesthetic Sensitivity as Ability

A systematic study of individual differences in aesthetic appreciation started as psychology was applied to education around 1900. Meumann (1908, 1919), the founder of experimental education, stated that empirical aesthetics should provide psychological explanations for aesthetic creation and appreciation, establish aesthetic norms, and award art a key place in the history of human civilization (Nadal & Ureña, 2021). Even if none of the aesthetic sensitivity proponents overtly mentioned these statements, the first was the maxim for the *responsiveness* notion, and the other two became the basis for normative conceptions of aesthetic sensitivity.

Initially considered an aspect of intelligence or educational aptitude and, thus, measurable through mental tests, psychologists looked for efficient measures of artistic ability for instruction and vocational guidance purposes (Burt, 1929, 1933; Meier, 1926, 1927, 1928; Thorndike, 1916, 1917). Accordingly, as part of his mental tests, Thorndike developed a measure of children's drawings merit based on psychophysical scaling rules (Thorndike, 1913, 1924), and measures of aesthetic merit and appreciation ability based on agreement (Thorndike, 1916) and disagreement (Thorndike, 1917) with consensus on liking for simple images. He also compared *good taste* between communities (Powel, Thorndike, & Woodyard, 1942; Thorndike, & Woodyard, 1943), concluding that it seemed "positively associated with differences in the intelligence, morality, and competence of their residents" (Thorndike, & Woodyard, 1943, p. 59). Likewise, McAdory (1929) developed a measure of art taste based on rankings according to academic grades (Siceloff & Woodyard, 1933), and Binet and Simon's (1916) scale of intelligence included pairs of *prettier*/*uglier* drawings of faces.

Among such measures, Meier (1927, 1928, 1939) argued that *aesthetic sensitivity*, defined as "the ability to recognize compositional excellence in representative art-situations, or the ability to 'sense' quality (beauty?) in an aesthetic organization" (Meier, 1928, p. 185; also 1939), was the most efficient and predictive. This concept was also referred to as *aesthetic perception* and *aesthetic judgment* (1926), encompassed by *aesthetic intelligence* (Meier, 1939)—although the distinctions are unclear (Clark, Zimmerman, & Zurmuehlen, 1987). Meier and Seashore (1929; also Meier, 1942) developed the Art Judgment Test. Later, Meier (1940) issued the Meier Art Tests: I. Art Judgment, premised upon the belief that the aesthetic character of art resides in the organization of parts according to universal principles of goodness, although determined by varying norms—e.g., depending on age and education—, and that the purpose of aesthetic judgment is to detect them. The Meier Art Tests: II. Aesthetic Perception (Meier, 1963) were designed to assess the *perceptual-facility* factor of artistic talent, i.e., the ability to detect subtle aspects of aesthetic significance. For Meier, aesthetic sensitivity was a measure of agreement with norms of artistic value determined by the original artworks versus their distortions—following Abbott and Trabue's method (1921), or the so-called *controlled–alteration process*. Hence, it was robust to criticisms like Farnsworth and Misumi's (1931) claims that the *better* pictures were not significantly preferred over the *worse* ones—appealing to general consensus as criterion for aesthetic norms. In addition, Meier (1934, 1939) asseverated that aesthetic sensitivity was independent of intelligence and subject to development on a biological basis.

The origin of the two main traditional conceptions of aesthetic sensitivity can be found here: On the one hand, Thorndike (1916, 1917) pioneered measures of aesthetic merit based on consensus and linked to intelligence, giving rise to the *determinist* view. On the other, Meier (1940, 1963; Meier & Seashore, 1929) defined aesthetic sensitivity as agreement with experts and educable, hence leading to *educative* views.

5.1. The determinist view.

Cyril Burt was the leading figure and pioneer of the *deterministic* notion of aesthetic sensitivity. He was strongly drawn to Galton's ideas, especially statistics, individual differences, mental tests, and eugenics, in which he started working with McDougall, Spearman, and Pearson in 1907 (Boring, 1950; Burt, 1962; Hearnshaw, 1979; MacKenzie, 1976). In 1909, he applied Spearman's general intelligence model to children, defining his life's work in quantitative intelligence testing, inheritance, and eugenics. He concluded that upper-class children performed better due to innate differences (Burt, 1909). In 1913, Burt was appointed part-time Chief Psychologist for the London County Council (Arnold, 2013) and kept much involved in British child guidance until 1931, when he succeeded Spearman (Wooldrige, 1994). He deemed incontrovertible that intelligence and mental abilities were genetically based, the main determinants of social position, and objectively and accurately measurable using mental tests (Norton, 1981). Consequently, he introduced them into the education system and systematically used children's performance to establish the vocational path fitted to their *natural* aptitudes. His battery included several tasks of literary, musical, and visual appreciation and creation.

Burt found two factors driving aesthetic appreciation. Analogous to the general intelligence factor, what he called a *general factor of artistic ability* accounted for *good taste*, defined as the ability to appreciate relations among elements in art, music, and poetry (Burt, 1933, 1949, 1960). For him, this factor was unitary, inherited, unalterable, measurable through simple tests, and explained most variance (Bulley & Burt, 1933; Burt, 1960). In his view, akin to intelligence, aesthetic appreciation should be measured according to expert judgment, which established the *true order* in rankings of value (Burt, 1939). Initially, he claimed that a special or group factor for musical ability existed over and above the general factor for intelligence (Board of Education, 1924; Burt, 1927). Spearman cast doubt on this and other group factors and attributed any apparent "unitariness presented by musical ability [and most other] special abilities [to] past experience rather than to native aptitude" (Spearman, 1927, p. 242). Later, Burt (1967; see also Dewar, 1938) considered the *general factor of aesthetic appreciation* as part of the more general *g*—for *genius* or *intelligence*. However, according to Valentine, intelligence had no impact on preference for musical intervals (Myers & Valentine, 1914; Valentine, 1913b, 1914), and Karwoski and Christensen (1926) concluded that artistic taste was only slightly dependent upon general intelligence and likely reflected a special native gift or a very early acquired talent. Even Eysenck later asserted that the general aesthetic factor was unrelated to intelligence (Eysenck, 1983).

A second bipolar factor distinguished between *objective* or *classical* and *subjective* or *romantic* types (Burt, 1915, 1933)—resembling Bullough's types (1908, 1910). It was more pronounced when controlling for the first factor and for younger or less artistically sophisticated, for which "irrelevant factors become more obvious" (Stephenson, 1936), and the impact of subjective associations increase (Burt, 1915; Dewar, 1938). This twofold factor was deemed analogous to those in Binet's (1903) intelligence tests and Burt's (1912) temperamental differences and close to Jungian *extravert*/*introvert* types (Dewar, 1938). Wing (1941) also found a general factor of musical ability and appreciation related to intelligence and a second factor distinguishing a *synthetic* type—concerned with appropriateness—from an *analytical* type—sensitive to changes—, which he compared to the above factors of intelligence and aesthetic appreciation.

Burt's powerful positions resulted in a broad, profound, and long-lasting influence at educational, social, political, and academic levels. This included his doctoral student Eysenck (Richards, 1997), who continued his psychometric approach to aesthetics. Eysenck's (1940) factor analysis uncovered a *general objective factor of aesthetic appreciation*. Faithful to his mentor, he asserted that it underlay performance on virtually any aesthetic appreciation test and was universal, largely determined biologically, and innate (Eysenck, 1941b, 1941c, 1942, 1981). He equated this factor *t* to the ability to appreciate objective beauty, that is, people's *taste*—hence its name—, or *aesthetic sensitivity* (Eysenck, 1941c, 1942, 1981). He described it as distinct—because "[this ability], independently of intelligence and personality, determines the degree of good or bad taste" (Eysenck, 1983, p. 213)—, general—for "it covers a large number of, probably all, pictorial tests" (Eysenck, 1940, p. 100)—, stable—as "[it] presumably [has] a genetic foundation in the structure of the nervous system" (Götz, Borisy, Lynn, & Eysenck, 1979, p. 801)—, and insensitive to experience—provided "[it] is independent of teaching, tradition, and other irrelevant associations" (Eysenck, 1940, p. 102)—and culture—given the "comparative absence of cultural factors determining aesthetic judgments" (Eysenck & Iwawaki, 1971, p. 817; Eysenck & Iwawaki, 1975; Soueif & Eysenck, 1971).

A second factor, *k*, identified by minimizing the influence of *t*, was bipolar (Eysenck, 1941a; Frois & Eysenck, 1995) and characterized by "brightness or intensity as opposed to darkness or lack of intensity" (Eysenck, 1983, p. 91). Thus, following Burt (1915, 1933) and Beebe–Center (1932), *t* was an expression of agreement, whereas *k* distinguished *types* (Eysenck, 1941a).

In Eysenck's (1941a, 1942) view, aesthetic sensitivity scaled as the degree to which liking approximated *true aesthetic value*, determined by either group or expert consensus (Eysenck, 1972a, 1981; Eysenck & Iwawaki, 1971). Eysenck's (1940, 1941c) *t* became for art and aesthetics what Spearman's *g* was for intelligence, such that if *g* could be scaled and measured, so could *t*. Namely, aesthetic sensitivity could be easily calculated by subtracting average liking ratings from either group averages or expert judgments. He first correlated individual liking ranks of artworks and objects with the average rankings (Eysenck, 1940). Later, he used simple geometric designs (Eysenck, 1972b; Eysenck & Castle, 1971) from Birkhoff (1933) and the Figure Preference Test (Barron & Welsh, 1952; Welsh & Barron, 1949). Finally, he developed the Visual Aesthetic Sensitivity Test (VAST; Chan, Eysenck, & Götz, 1980; Götz et al., 1979; Iwawaki, Eysenck, & Götz, 1979).

However, like the tests it intended to surpass—e.g., Design Judgment Test (Graves, 1948); Art Judgment Test (Meier & Seashore, 1929)—, the VAST exhibited low internal consistency and structural validity, and its scores were explained by intelligence, figural creativity, and personality traits (Chamorro-Premuzic & Furnham, 2004; Furnham & Chamorro-Premuzic, 2004; Myszkowski, Çelik, & Storme, 2018; Myszkowski, Storme, Zenasni, & Lubart, 2014; Payne, 1967). Thus, contrary to Eysenck's (1941a, 1942) claims, aesthetic sensitivity appeared not to be a distinct ability but to draw upon general cognitive processes, learning, and experience. To overcome these issues, Myszkowski and colleagues recently suggested two mutually compatible amends: First, Myszkowski and Zenasni (2016) proposed a composite measure of *aesthetic aptitude*, including aesthetic exploration, art expertise, sensitivity to complexity, aesthetic empathy, and aesthetic sensitivity as *aesthetic balance recognition*. Second, Myszkowski and Storme (2017) introduced a revised version with improved internal consistency and structural validity.

Crucially, the VAST only provided a measure of the ability to discriminate figures according to a particular understanding of harmony (Gear, 1986), also in its revised version (Myszkowski & Storme, 2017). Taking advantage of this, Jacobsen and colleagues (Marschallek, Weiler, Jörg, & Jacobsen, 2019) found that people striving for individuality exhibited lower VAST scores because they tended to violate norms to assert their uniqueness. Remarkably, Leder and colleagues (Mitrovic, Hegelmaier, Leder, & Pelowski, 2020) used the VAST to show that people spontaneously looked longer at their preferred designs, irrespective of whether *objectively better* according to experts.

Like the traditional concept of aesthetic experience upon which they rest, the normative conceptions of aesthetic sensitivity assume an absolute *truth* in aesthetic appreciation: *Aesthetic sensitivity* or *good taste* is defined as an ability to approximate *true order* (Eysenck, 1972a) or appreciating *absolute beauty* (Eysenck, 1972a; Eysenck & Iwawaki, 1971), as some objects are deemed *objectively superior* to others (Myszkowski et al., 2016). Noteworthy, this principle of *objectivity* in aesthetic judgments was also present in assessments other than liking or preferences—e.g., Leijonhielm (1967) defined *sensitivity to expresiveness* as agreement with group averages in rankings of the expressive qualities of forms and colors.

The *determinist* view just reviewed also maintains its inheritability. However, the claim for innatism—like that raised for intelligence in the same period—lacks empirical support, and that of insensitivity to experience contradicts most evidence, including some of Eysenck's (1972a, 1983) findings. Actually, development and learning are intrinsic to the conception of aesthetic sensitivity as the degree of agreement with expert judgment because expertise is inherently acquired.

5.2. The educative view.

Despite assuming the existence of objective aesthetic value and the supremacy of particular aesthetic judgments over others, the *educative* view embraces developmental and cultural learning of taste standards. In this sense, it departs from the *determinist* notion of aesthetic value as immutable—for it is relative to context—and innate—as it *must* be educated. This view permeated society (e.g., Dai & Shader, 2001) and led to institutional policies intended to *raise* public standards of taste (Suga, 2003). In academy, many philosophers (Mitchells, 1966), artists (Fehl, 1953; Smets & Knops, 1976), as well as psychologists and educators (Adler, 1929; Anderson, 1972, 1975; Bullock, 1971; Day, 1976; Gernet, 1940; Hahn, 1954; Hevner, 1930, 1934; Kwalwasser & Dykema, 1930; Kyme, 1967; Reimer, 1965, 1968a, 1968b; McElligot, 1919; Taunton, 1982; Trabue, 1923; Vernon, 1930; Webster, 1988a, 1988b) adhered to this trend. Beyond its prevailing instrumental use, this normative conception of aesthetic sensitivity was also object of psychological inquiry. For the sake of brevity and to keep the line of argument as compact as possible, I focus here on the most significant contributions in or very closely related to the field of empirical aesthetics.

A key aspect to understanding the development of conceptions of aesthetic sensitivity is what they considered to be the main determinant of aesthetic experience. In this regard, Lundin (1953) noticed how early research in empirical aesthetics fitted psychological philosophies of an earlier era, focused on the object rather than the subject, and accompanied by a belief in *inherent* powers or sensitivities. Instead, he argued that aesthetic responses were acquired and, therefore, culturally determined and subject to learning. This entailed a subtle but significant shift in the use of taste tests: from assessing aptitude to assessing achievement. Noteworthy, most tests mainly addressed perceptual or productive abilities, only including few items on aesthetic judgment or preference.

Relying on the existence of objective aesthetic value whose appreciation must be educated, scholars like Schoen (1923, 1925, 1927, 1928), although still object-oriented (Schoen, 1940), sought ways to assess and cultivate the appreciation of *correction*—i.e., *beauty*—in (Western tonal) music. Karwoski and Christensen (1926) went even further in establishing value (meta-)judgments—*correct*/*incorrect*—of reasons for value judgments—*good*/*bad*—of objects.

Reorienting the focus of investigation toward the subject, Hevner (1937; Hevner & Mueller, 1939) showed that information about the object modulated its aesthetic appreciation. Similarly, Voss (1936) observed notable improvement in aesthetic analysis and judgment in children aware of criteria for aesthetic merit, and Clair (1939) overtly refuted the condition of *disinterestedness* because “critical and appraising analysis of works of art (…) intensifies (…) [their] appreciation” (p. 67). Remarkably, Carroll (1932) showed that the relationship between the abilities to appreciate art, literature, and music was very slight. This not only discredited the determinist claim of *generality* but pointed to a modality-specific basis of aesthetic appreciation, even if according to standards.

Among other determinants of creativity, Barron and Welsh used aesthetic judgment under the notion of *good taste*, defined as the ability “to discriminate the good from the poor (as judged by experts)” (Barron, 1952, p. 387; 1963, 1969; Barron & Welsh, 1952). In Welsh’s (1949) study, the group with artists—representative of *good taste*—showed preference for complexity and asymmetry, dissident personality, and unconventional political views (Barron & Welsh, 1952). Barron (1952) confirmed that artists preferred complex and asymmetric figures, and were rebellious against authority and tradition (1953). The paintings artists liked at that time were “‘modern’ art movements as Primitivism, Expressionism, Impressionism, and Cubism” (Barron, 1952, p. 391), known for revolting against traditional ways in art—thus evincing the mutable character of expert opinion and, consequently, of aesthetic sensitivity as agreement with expert judgment.

Irvin Child was the central proponent of this *educative* conception of aesthetic sensitivity in empirical aesthetics. Child (1962) was skeptical about Eysenck’s assumptions that average rankings represented true aesthetic value, and that the extent to which individual preference agreed with the average constituted a valid measure of aesthetic sensitivity, so he submitted them to empirical examination. Child (1962) tested preference versus aesthetic value as determined by experts, pointing out the disparity of preferences, contrasting with a higher agreement observed between expert judgments of aesthetic value. He derived a measure of aesthetic value as the average rating of expert judges weighted by agreement with the other judges and compared it with non-experts' averaged preferences, realizing that both bore little relation. Furthermore, he found that "the degree to which preferences are related to aesthetic value is a very stable characteristic of the individual (…) [and that the] degree of agreement with an aesthetic standard is an even more consistent characteristic than [the] degree of agreement with group preferences" (Child, 1962, p. 504). Finally, he found negative or no correlation between individual measures of preferences defined as the extent to which they resemble one kind of standard or the other. He concluded that "the degree of agreement between one's preferences and aesthetic value is an index of aesthetic sensitivity (…) [whereas the] degree of agreement with group preferences does not correspond to an external criterion of aesthetic sensitivity" (p. 506).

In Child's (1962, 1965) view, aesthetic sensitivity or good taste was cultivated with practice and resulted not from a specific ability but from general cognitive style and personality (Child, 1964, 1965; Iwao & Child, 1966). For him, high aesthetic sensitivity was the manifestation of an "actively inquiring mind, seeking out experience that may be challenging because of complexity or novelty, even alert to the potential experience offered by stimuli not already in the focus of attention" (Child, 1965, p. 508). Thus, a highly sensitive person would be "interested in understanding each experience thoroughly and for its own sake rather than contemplating it superficially and promptly filing it away in a category, and able to do all this with respect to the world inside himself as well as the world outside" (p. 508)—emphasizing the relevance of motivation, theoretical interest, and personal and contextual factors. Therefore, he conceived aesthetic sensitivity more as a trait epitomized by experts than as an ability in a strict sense.

Accordingly, Child (1964, 1965) defined aesthetic sensitivity as "the extent to which, when a person judges the esthetic value of works of art, his judgments agree with an appropriate external standard of their esthetic value (…) provided by the judgment of experts" (Child, 1965, p. 476). Child's (1965) Test of Esthetic Sensitivity was based on Bulley's (1951) and allowed him to find some cross-cultural expert agreement (Ford, Prothro, & Child, 1966; Iwao & Child, 1966).

Eysenck (1972a) underlined the ambiguity of Child's definition in whether *judgment* (or *response*) denoted *preference for* or *recognition of* aesthetic value. Child stated that "aesthetic sensitivity is expressed in a tendency to prefer the aesthetically good" (Child, 1962, p. 508). However, he also asserted that "[i]f one set out to measure aesthetic sensitivity, he would ordinarily not ask people to express personal preferences, he would generally do better to ask them to make aesthetic judgments, as in the Bulley Test" (p. 510). Eysenck claimed that his notion referred to the ability to appreciate beauty (Eysenck, 1941c, 1942, 1981), but it also "determine[d] the degree of good or bad taste" (Eysenck, 1983, p. 213), and he used *aesthetic sensitivity* and *taste* indistinctly. Thus, for both, aesthetic sensitivity was a measure of the ability to make aesthetic judgments according to standards of value, manifested in preferences in agreement with those standards.

Parsons and colleagues advocated for the necessary distinction between *aesthetic responses*, *preferences*, and *judgments*, of which only the latter are about the object, and thus only those "*can* be relevant or irrelevant," meaning susceptible of value judgments; whereas responses "cannot validly be categorized as 'appropriate or inappropriate', or 'relevant or irrelevant'," and one "cannot be better or worse at having preferences" (Bamossy, Johnston, and Parsons, 1985, pp. 64–65). For them, instruments such as Welsh's (1959; Barron & Welsh, 1952; Welsh & Barron, 1949), Graves's (1939), Thorndike's (1916), and the National Assessment of Art Education's (1981) "have not observed this distinction and consequently seem to lack validity" (Bamossy et al., 1985, p. 65).

Parsons and colleagues stressed that manipulating masterpieces was a standard technique in artistic movements like Pop Art, so they questioned the utility of tests based on comparisons between originals and alterations and emphasized expert judgment's mutable character. They criticized the *direct* use of expert judgment in Child's (1962), Graves's (1939), Meier's (1940), Welsh's (1959; also Barron & Welsh, 1952; Welsh & Barron, 1949), Thorndike's (1916), Bottorf's (1946), and Williams and Hattwick's (1932) tests, as it is "easier to get agreement among experts on reasons for judgments than on judgments themselves" (Bamossy et al., 1985, p. 67). Consequently, they disregarded the prevailing notion of aesthetic sensitivity while defended the existence of objective value and the utility of assessing aesthetic ability. Their Aesthetic Judgment Ability test (Bamossy et al., 1985) rested upon the theory of *cognitive development of aesthetic judgment* (Parsons & Durham, 1979; Parsons, Johnston, & Durham, 1978) and measured judgments' sophistication, with expert criteria representing higher-stage reasons for aesthetic judgments—resembling Karwoski and Christensen's (1926) approach.

Winner, Rosenblatt, Windmueller, Davidson, and Gardner (1986) studied the development of aesthetic sensitivity in children, finding that it was art-form-specific—i.e., not a single factor—and property-specific—i.e., multiple. In this line, Elliot (1995) asserted that "it is highly doubtful that there is any such general capacity as aesthetic sensitivity. Multiple intelligence theories and contemporary studies of creativity argue against such possibility" (p. 249).

Exemplifying the multiplicity of meanings attributed to the term, Smolewska, McCabe, and Woody (2006) put forward an alternative conceptualization of aesthetic sensitivity: a subscale of the sensory-processing sensitivity trait accounting for awareness of aesthetic stimuli, likely driving approach behaviors and enhancing personal well-being (Sobocko, & Zelenski, 2015). Even if not explicitly normative, this construct also assumed the existence of special *aesthetic objects* or special *aesthetic qualities* that people are more or less apt at detecting.

5.3. Discussion

From the traditional perspectives reviewed, aesthetic experiences might seem contemplative, recreational, and a luxury unconnected to survival. However, this departs from the reality of art creation and appreciation. It was contested by *avant-garde* movements and art theory already in the dawn of empirical aesthetics, rejecting the entangled assumptions of distinct aesthetic dispositions and objects, and the privileged status of aesthetic experience, with *aesthetic sensitivity* or *taste* as its main indicator (Nadal, 2020; Skov & Nadal, 2020b). Besides, the philosophical appropriateness of the traditional notion of aesthetic experience was amply questioned (Cohen, 1964; Dickie, 1964, 1965; Kennick, 1958; Santayana, 1904). Even more critical here, psychological and neuroscientific arguments disproving these traditional conceptions of aesthetic experience were also put forward by figures like Berlyne (1971, 1974), Gibson (1975), and, more recently, Skov and Nadal (2020a, 2020c).

As observed throughout the literature review, normative views of aesthetic sensitivity impose value judgments (*good*/*bad*) on judgments of hedonic value (*like*/*dislike*), aligned with the traditional idea of aesthetic experience. Nadal and colleagues (Corradi, Chuquichambi, Barrada, Clemente, and Nadal, 2020) challenged this Western, elitist, and prescriptive notion of *good taste* and the existence of *objective beauty*. They presented compelling reasons to doubt the usefulness of traditional constructs and measures of aesthetic sensitivity, even if revised. Aesthetic sensitivity as the appreciation of objective beauty—qualified as *good*, *appropriate*, *superior*, or similar—is meaningful and useful only if beauty is truly an objective value, inherent to the object, and if group averages or expert judgments can determine such a value. Scientific knowledge urges to reject both premises.

The first premise is an expression of naïve realism, refuted by basic facts of perception and cognition (Corradi et al., 2020). As Farnsworth (1950) put it:

> It is a truism that people of each culture area are likely to regard their art forms as God-given and superior to those of their neighbors. But, unless the absolutist accepts the mythology of racism and believes that the composers of his group alone have discovered the ‘true’ standards of musical taste, he can take no comfort from anthropology. (p. 23)

For Farnsworth (1958), preference is acquired through exposure to stimuli pertaining to the individual’s developmental context. Therefore, it should be considered an eminently sociocultural phenomenon in which social factors—e.g., peer pressure and conformity—, familiarization, experience, and training are manipulable and the primary determinants of musical preferences (Farnsworth, 1926a, 1926b, 1926c, 1932a, 1932b).

According to Arnheim (1964, 1966, 1969), aesthetic appreciation fundamentally arises from an active, dynamic perception of the *directed tensions* conveyed in the stimuli because of individual experience and disposition, which constitutes a general ability (Arnheim, 1961). These claims contradict the belief in special objects, dispositions, and abilities and point to the interaction between the object and the subject emphasizing the active nature of perception and appreciation.

Integrating these approaches, research shows that beauty is not an attribute of objects we are more or less apt at detecting and appreciating. Quite the opposite, it is an attribute of our experience of objects, actively constructed by brain systems that seek to make meaning of such objects, their features, and their value to us (Nadal, Gallardo, & Marty, 2017), based on expectations and predictions, beliefs, experience, and context (Corradi et al., 2020).

The second premise, the belief in immutable aesthetic value—immanent in the *determinist* view—, is refuted by historical fact: Aesthetic value changes with time and perspective. This is evinced in the negative correlations between Meier's and Child's tests (Stallings & Anderson, 1969), the disagreement between experts (Bamossy et al., 1985), the limitations of tests based on a particular expert criterion (Gear, 1986), and the mutability of associations and values linked to different art movements (Barron, 1952). Aesthetic value is historically and culturally relative (Jacobsen, 2006), and thus, in no meaningful sense *true* or *inherent* (Corradi et al., 2020).

Notably, Eysenck argued for aesthetic sensitivity's *universality*, *innateness*, and *insensitivity to experience* based on an absence of cultural influences only comparing averaged judgments of students, not experts (Eysenck & Iwawaki, 1971, 1975; Soueif & Eysenck, 1971). In contrast, Child's cross-cultural research program focused on experts, arguing for some cross-cultural expert agreement (Ford et al., 1966; Iwao & Child, 1966; Iwao et al., 1969). However, these studies are questionable in their sample sizes and composition (Che, Sun, Gallardo, & Nadal, 2018), especially those used to support the generality and artistic specificity of aesthetic sensitivity (Child, 1965, 1981).

The shift of the external reference from general to expert consensus—as defining either *objective beauty* (Eysenck, 1941c, 1942) or *true aesthetic value* (Child, 1965)—might seem striking in *determinist* approaches (Chan et al., 1980; Götz et al., 1979; Iwawaki et al., 1979) because it contradicts the conditions of *innateness* (Eysenck, 1941b, 1941c, 1942, 1981) and *insensitivity to experience* (Eysenck, 1940, p. 102) and culture (Eysenck & Iwawaki, 1971, p. 817; Eysenck & Iwawaki, 1975; Soueif & Eysenck, 1971), if one acknowledges that expert opinion is mutable and context-dependent. However, this apparent antinomy may be dissolved by considering the function that each notion served: According to the determinist view, the ability to appreciate objective beauty allowed for a professional career in the arts, so that expertise would be primarily determined by early abilities assumed to be innate. In this scenario, both general and expert consensus would tap into the same phenomenon.

In contrast, the educative view advocated for cultivating the capacity to appreciate true aesthetic value according to authoritative (expert) standards. In other words, aesthetic sensitivity turned into a measure of achievement. Noteworthy, assuming general consensus or expert consensus implies a different position and function of the standard within the population: Whereas group consensus reflected an underlying general ability to appreciate an object property like *objective beauty*, immanent to human nature and immutable, the reference for the ability to appreciate *true aesthetic value* was defined by an elite and constituted an archetype to pursue (see Figure 5).

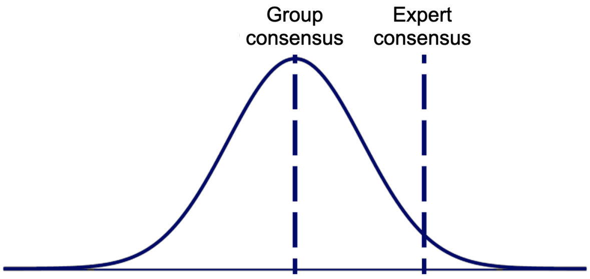

Figure 5. Standards of taste and aesthetic value in the general population (adapted from Che, Sun, Gallardo, & Nadal, 2018). According to traditional notions of aesthetic sensitivity, the closer to the given norm, the *better* the taste or the *higher* the aesthetic sensitivity.

Further discussion on cross-cultural agreement in taste unveils an interesting phenomenon: Studies other than Eysenck's and Child's unraveled that "there is no general agreement [in preferences] which extends beyond the cultural boundaries" (Lawlor, 1955, p. 690; also McElroy, 1952). A recent review of cross-cultural aesthetics suggested moderate cross-cultural agreement reflecting the influence of general cognitive abilities, creativity, personality traits, and art interest and knowledge (Che et al., 2018). In this vein, North and Davidson (2013) found some agreement in musical taste according to education and employment despite regional differences, and interactions between education, employment, and region in uses and typical emotional reactions to music. In short, sociocultural and personal factors in interaction appear to be key determinants of appreciation, involving similarities derived from convergent social and personal factors—e.g., expertise—, and differences resulting from divergent cultural, social, and personal factors.

Fundamental scientific questions inevitably arise from this analysis: What is the scientific use of assessing compliance with a norm? Does it contribute to understanding the psychological nature of appreciation? In response to the first, Lambrou, Veale, and Wilson's (2011), Marschallek et al.'s (2019), and Summerfeldt, Gilbert, and Reynolds's (2015) studies exemplify scientific advantages of inquiring into the phenomenon of compliance, addressing its motivations, development, or relation to personality and psychic disorders. As for the second, compliance with norms of *aesthetic value* could be expected to impact appreciation as a motivational factor. However, according to Mitrovic et al. (2020), it appears to be unrelated to preferences.

In summary, the fundamental claims of both notions of aesthetic sensitivity have been disproved by scientific evidence. On the one hand, proponents of the *determinist* notion argued for the existence of a uniquely human, biologically-based, immutable (Eysenck, 1941a, 1941b, 1942, 1981), universal (Eysenck & Iwawaki, 1971, 1975; Soueif & Eysenck, 1971), and general factor of aesthetic appreciation (Burt, 1933; Eysenck, 1940), which was unrelated to experience (Eysenck, 1940), and personality (Eysenck, 1983). However, such a biological determinism is arbitrary and scientifically unsupported: Aesthetic appreciation seems to depend on culture, sensory modalities, and kinds of materials and features (see section 6). Besides, the instruments used by the *determinist* notion are deficient and related to intelligence, creativity, and personality (Chamorro-Premuzic & Furnham, 2004; Furnham & Chamorro-Premuzic, 2004; Myszkowski et al., 2018; Myszkowski et al., 2014; Payne, 1967). On the other hand, promoters of the *educative* notion advocated for the dependence of aesthetic appreciation on artistic traditions and criteria, culturally bounded, and linked to personality, so that experts were the unique authorities for aesthetic sensitivity (Child, 1962, 1964, 1965; Iwao & Child, 1966). However, the methodology employed in these studies (Child and Iwao, 1968; Ford et al., 1966; Iwao and Child, 1966; Iwao, Child, & García, 1969), and in particular, of those used to claim the generality and aesthetic specificity of sensitivity (Child, 1965, 1981) also suffer from methodological flaws (Che et al., 2018). But even more crucially, both approaches are insurmountably limited by an arbitrary extrinsic normativity and assumptions that run against a wealth of psychological and neuroscientific evidence (Corradi et al., 2020; Nadal, 2020; Skov & Nadal, 2020a, 2020b, 2020c). Furthermore, it is unclear how these approaches may contribute to understanding appreciation.

6. The Quest for Understanding Appreciation: Aesthetic Sensitivity as Responsiveness

To be meaningful and useful, the construct of aesthetic sensitivity, like any psychological construct, needs to concord with established psychological and neuroscientific knowledge and advance the understanding of psychological phenomena (Corradi et al., 2020). The normativism reviewed in the previous section (5) was not the only trend in empirical aesthetics and did not reflect or agreed with contemporary knowledge. Indeed, alternative views on aesthetic experience and appreciation predated and coexisted with normative notions. They gave rise to a different conception of aesthetic sensitivity and related constructs. Their scientific value is not limited to assessing compliance with norms, since they were devised as means to understand the nature of appreciation and its underlying psychological mechanisms.

In 1876, Fechner originally conceived empirical aesthetics as applied psychophysics to identify the lawful manner in which the mind translates stimulus properties into appreciation (Murphy, 1929). More specifically, he devised it as part of his more general hedonics to investigate sensory pleasure (Nadal & Ureña, 2021; Clemente, Pearce, & Nadal, 2021).

Coetaneous with the booming of traditional notions, Berlyne (1970, 1971, 1974) understood aesthetic activities as intrinsically motivated stimulus-seeking behaviors reinforced by experience with stimulus patterns. For him, the purpose of empirical aesthetics was to understand the regulation of hedonic tone. According to Berlyne (1971), hedonic tone, defined as the capacity to reward an operant response and elicit preference or pleasure, depends on the stimulus' arousal potential and the organism's current arousal level. As organisms tend to seek the optimal hedonic value, they expose themselves to and judge stimuli as a function of their arousal potential. Hedonic tone relies on the potential information transmitted to the organism through psychophysical, ecological, and collative features—e.g., novelty, surprise, complexity, ambiguity, or asymmetry. Thus, Berlyne's explanation of aesthetic appreciation was grounded on basic functions of brain reward and aversion systems (Che et al., 2018), and was incompatible with any normative ability of appreciation—even more at odds if thought of as uniquely human, universal, stable, innate, and unrelated to experience and culture. Berlyne's work exerted a lasting influence on research in empirical aesthetics and related fields (Che et al., 2018; Jacobsen, 2006; Nadal & Ureña, 2021; Silvia, 2005).

Recently, Skov and Nadal (2020a) proposed the discipline of aesthetics as dedicated to investigating aesthetic appreciation, which is just another name for *sensory valuation* (Skov, 2019). Sensory valuation is the study of the role of sensory information in the computation of hedonic value, linking hedonics—i.e., the study of hedonic valuation itself—and neuroeconomics—i.e., the study of hedonic values' integration into decision-making and behavioral control—, and consequently assuming a central position in psychology and neuroscience. Hedonic values are responses to projections from sensory systems to distributed nuclei in the reward system, modulated by input from the interoceptive and executive systems—signaling homeostatic state and contextual information relevant to the valuation event (Bartra, McGuire, & Kable, 2013; Becker et al., 2019; Berridge & Kringelbach, 2015; Brown, Gao, Tisdelle, Eickhoff, & Liotti, 2011; Sescousse, Caldú, Segura, & Dreher, 2013). They are not uniquely human and can be deemed affective states that motivate behavior according to individual and contextual factors (Skov, 2019, 2020; Skov & Nadal, 2020a).

These frameworks are integrated and understood in terms of contemporary scientific knowledge and have advanced the understanding of aesthetic appreciation or, more accurately, *sensory valuation* (Skov, 2019). Contrary to the traditional notion of aesthetic appreciation, sensory valuation is a function of an active and predictive animal and a fundamental aspect of cognition, necessary to organize behavior, and thus, fully connected to survival (Nadal, 2020; Skov & Nadal, 2020a).

Between these landmarks in empirical aesthetics, many researchers have contributed research on the appreciation of sensory objects within broad scientific frameworks. Notably, Gordon (1896) anticipated the *common currency* hypothesis, providing a unified psychological account of economic, logical, ethical, and aesthetic value, defined as agreeableness or pure sensuous pleasure—disbelieving the *specialness* of aesthetic experience. For Gordon (1903), the psychological measure of value was the intensity of its concomitant pleasant feeling and the complexity and associations of the valued content.

As for the nature of valuation mechanisms, Peters (1942) understood aesthetic experiences as perceptual experiences focused on value. He deemed them affective states operationalized in terms of value judgments of *pleasantness/unpleasantness*, *good/bad*, *attractive/repulsive*, that organisms assign to objects (Peters, 1935). Such affective states were responses to the objects' psychological or conceptual meaning, resulting from inherited predisposition, motivational selection, and association (Peters, 1955). Crucially, this conception did not exclude non-human organisms—discrediting the *uniqueness* of aesthetic value.

Remarkably, Angier criticized the assumption that group averages approximating the golden section corresponded to a norm of aesthetic pleasingness, while deviations from it were treated as errors. Consequently, he inspected to what extent averages reflected individual ratings (Angier, 1903), confirming that the golden section is not a universal aesthetic norm but a mathematical abstraction resulting from averaging across participants (Green, 1995).

Davis even declared the “fallaciousness of attempts to establish a ‘golden section’ based upon averages, either of the preferences of a group of *Ss* or of a number of preferences from a single *S*” (Davis, 1933, p. 302; Haines & Davies, 1904). These early approaches cast doubt on much research in empirical aesthetics based on averaging across participants and raise the fundamental question of their utility to investigate psychological processes. Indeed, understanding differences in how people value objects is crucial to understanding the valuation process itself.

In this regard, Martin (1905, 1906) found remarkable differences in individual aesthetic judgments. Twenty years after formulating the psychological measure of value, Gordon (1923) found high intra-individual reliability over time and low inter-individual agreement in beauty rankings. From the enormous individual differences in preferences observed in the literature, Chandler (1934) concluded that “the human organism is not so constituted as to react in a definitive way to each color or each combination of colors” (p. 114)— refuting the *determinist* view—, and attributed preferences to “a multitude of factors that vary with individual observers and changing circumstances” (p. 115)—putting into question the utility of standards of aesthetic value. In 1938, Chandler and Barnhart put together a comprehensive bibliography of empirical aesthetics. Two years later, Barnhart (1940) based his study of aesthetic preference on three kinds of interests or criteria—*formal*, *connotative*, and *design potentiality*—, revealing wide variability not only in individual preferences but in the criteria at their basis.

Digging into the nature of individual differences in the valuation of sensory objects, Washburn introduced the concept of *affective sensitiveness* to distinguish between people with a strong tendency to like and dislike materials of different sorts—e.g., tones, colors, and speech sounds—from people relatively indifferent to them (Babbitt, Woods, & Washburn, 1915; Clark, Quackenbush, & Washburn, 1913). Affective sensitiveness was calculated as “the ratio of the sum of the number of judgments of extreme pleasantness and extreme unpleasantness to the number of judgments of indifference” (Washburn, Hatt, & Holt, 1923, p. 105; Clark et al., 1913). It depended on circumstances and conditions such as fatigue—reducing it (Robbins, Smith, & Washburn, 1915)—, art interest—leading people to approximate expert’s rankings (Cattell, Glascock, & Washburn, 1918)—, and experience and expertise in art and aesthetics—increasing it (Washburn et al., 1923). Affective sensitiveness captured differences in the magnitude of individual responsiveness to visual and auditory stimuli, but not individual responsiveness to variations in specific stimulus features. Thus, it did not relate the increase in response to the increase in stimulation—departing from Fechner’s (1876) psychophysical conception of empirical aesthetics.

By contrast, Marcos Nadal and colleagues defined *aesthetic sensitivity* as the extent to which a specific feature influences someone’s liking, and measured it as the individual slope in linear mixed-effects models (Corradi et al., 2020). Thus, they provided a means to study sensory valuation by assessing the relevance of particular features in the computation of hedonic value for each individual in a particular context. In other words, they inquired into the nature of individual differences in sensory valuation. To that end, they asked non-experts to rate their liking for visual designs (Corradi et al., 2020) and musical motifs (Clemente, Pearce, & Nadal, 2021) varying in balance, contour, symmetry, or complexity.

In a series of studies, Nadal and colleagues showed that people differ in the extent to which they rely on balance, contour, symmetry, and complexity when assigning hedonic value to visual designs (Corradi et al., 2020) and musical motifs (Clemente et al., 2021). That is, their results uncovered multiple aesthetic sensitivities: One may be sensitive to some features but not others, and each sensitivity varies individually. Additionally, aesthetic sensitivities barely related to other individual differences and, if so, they did it in a modality- and feature-specific way (Clemente, Pearce, Skov, & Nadal, 2021; Corradi et al., 2020). Aesthetic sensitivities also revealed stable in time in both the visual (Corradi et al., 2020) and auditory modalities (Clemente, Pearce, & Nadal, 2021). Remarkably, people tended to cluster into two distinct profiles according to their musical aesthetic sensitivities, also stable in time (Clemente, Pearce, & Nadal, 2021). In addition, aesthetic sensitivity to visual curvature seemed to be consistent across kinds of visual objects (Corradi et al., 2019). The assessment of visual and musical aesthetic sensitivities within individuals revealed that liking judgments rely on modality-specific representations of visual and auditory features, rather than abstract modality-general balance, symmetry, or complexity (Clemente, Pearce, Skov, & Nadal, 2021). In contrast, liking for visual and melodic contour may reflect differences in general sensitivity to negative and arousing affect due to potential threat and uncertainty inherent to jagged melodies and sharp objects, and, conversely, positive and calm affect elicited by smooth music and curved figures (Clemente, Pearce, Skov, & Nadal, 2021). In brief, this conception of aesthetic sensitivity unraveled that hedonic value (liking) is computed based on modality-specific and feature-specific sensory information, whose relevance varies consistently for each individual and feature, transcends object kinds—at least for visuals varying in contour—and tends to converge across musical features into stable sensitivity profiles.

Beyond these findings, Nadal and colleagues' approach poses new questions and fosters further research. To illustrate this, it is worth mentioning some examples of feasible future research: First, it remains unclear whether, as is the case for visual contour, aesthetic sensitivities to other features transcend kinds of visual or musical objects. Second, addressing other attributes and sensory modalities constitutes a clear line of study. Third, also important is to understand the factors modulating aesthetic sensitivity, such as exposure or context. Fourth, investigating the impact of temperamental traits such as apprehension or anxiety on aesthetic sensitivity is key to elucidate which and how psychological factors interact with sensory information to determine the computation of hedonic value. Fifth, it stands to reason to search for neurobiological explanations for differential sensitivities, such as enhanced or reduced connectivity between sensory systems and the reward system. Lastly in this shortlist of suggestions, elucidating the contribution of genetic factors like, e.g., predisposition to affective sensitivity, may advance the understanding of the biological basis and role of affective processes in sensory valuation.

To summarize, these approaches to sensory valuation based on individual responsiveness to object features are knowledge-driven: They emerge from and are intended to satisfy a genuine interest in understanding psychological processes. Individual differences are neither considered deviations from the standard nor resulting from irrelevant factors (e.g., Burt, 1933). Instead, they are vital to understanding psychological processes of valuation, whose primary drives are precisely the factors disregarded by traditional views. Contrary to traditional notions of aesthetic sensitivity, Nadal and colleagues' approach aligns with current knowledge and contributes to shedding light on sensory valuation.

7. Conclusion: Major Challenges, Goals, and Suggestions

In the traditional notions, aesthetic sensitivity was defined as the ability to appreciate standards of aesthetic value. The traditional views differ in the ascribed emphasis or relevance of biological and cultural factors in such an ability and its mutability: Whereas the *determinist* view stressed its biological foundations and immutable character, the *educative* view highlighted its developmental quality. Consequently, the *determinist* view supported and fostered typecasting and segregation policies, whereas the *educative* view promoted formative and indoctrinating programs. Alternative approaches, on the contrary, responded to a genuine, epistemic interest in understanding appreciation. Whereas the scientific contribution of traditional views seems narrow in this regard, defining aesthetic sensitivity as *responsiveness* to variations in stimulus features affords promising prospects—judging by its achievements in its relatively short life.

The core distinction between these approaches lies in the consideration of individual differences in appreciation and the factors underlying them. As Table 1 illustrates, these three conceptions of aesthetic sensitivity can be further synthesized in terms of appreciation's *origin*, *plasticity*, and *reference*: First, the *determinist* view emphasized its biological origin and immutable character in reference to an extrinsic, objective truth. Second, the *educative* view stressed its cultural origin and developmental nature, governed by an also external but subjective, mutable rule. Third, the *responsiveness* notion claimed its endogenous origin and transitory, ephemeral nature, determined by an intrinsic, embodied account of contextual and individual factors in relation to sensory input for the computation of hedonic value.

Table 1. *Defining Features of Aesthetic Sensitivity Notions as for the Nature of Appreciation*

	Determinist	**Educative**	**Responsiveness**
Origin	Biological	Cultural	Biocultural
Plasticity	Immutable	Developmental	Transient
Reference	Exogenous	Exogenous	Endogenous
Object	Special	Special	General
Mechanism	Special	Special	General
Faculty	Human	Human	Animal
Factor	General	Specific	Specific

Further divergences derive from these distinctive qualities regarding the *object* and *mechanism* of appreciation, the *faculty* for appreciation, and the *factors* affecting it: Regardless of whether biologically- or culturally-based, norms as references for appreciation concern or distinguish special qualities, attitudes, capabilities, mechanisms, and objects eminently human; whereas responsiveness relies on general neurobiological valuation mechanisms common to other animals. Besides, emphasizing a single factor of appreciation implies it being modality- and feature-general, whereas experience-based approaches acknowledge a multiplicity of factors driving appreciation, and thus, of aesthetic sensitivities, which tend to be modality- and feature-specific (Table 1).

As Danziger (1997) noted, considerable theoretical work is implicit in the categories used to describe and classify psychological phenomena, for their meaning carries an enormous load of unexamined and unquestioned assumptions and preconceptions. In the case of aesthetic sensitivity, these are inherited from the conceptual framework from which the idea of aesthetic experience emerged, fruit of social and philosophical transformations in Europe during the 18th and 19th centuries. The conceptualization of aesthetic experience assumed a categorical distinction between aesthetic and non-aesthetic experiences, making empirical aesthetics' primary goal to identify what makes aesthetic experiences *special* and different from other experiences, as for the objects, emotions, or attitudes involved, or comporting a *uniquely* human capacity (Nadal, 2020).

However, this 19th-century philosophical aesthetics is far removed from current scientific concerns and practices. Most beliefs and methods of that era have been discredited and abandoned in the light of scientific advancements. Why a construct disconnected from current scientific knowledge is in use in science seems dystopian and is only detrimental to the discipline: hampering scientific progress, misleading researchers into seeking psychological and neural underpinnings of a non-existing psychological entity, creating special models, and hence, severing empirical aesthetics from other domains of psychology and neuroscience (Nadal, 2020; Skov & Nadal, 2020a).

This paradox pervades the concept and name of aesthetic sensitivity. As for the concept, the primary conclusion from this critical review is that the only way forward is to discard the traditional notions of aesthetic sensitivity and to test the only notion consistent with current established scientific knowledge and useful to understanding sensory valuation (see also Corradi et al., 2020).

The name still requires some discussion. Whereas the terminology to designate aesthetic sensitivity is multiple and sometimes diffuse, the constructs it traditionally denotes are stable. The very term *aesthetic sensitivity* is central to the normative views and by no means fortuitous or innocuous: First, it has been made substantive as *sensitivity*—from Latin *sentire*, feel—, that is, the capability to sense or respond to sensory information, as defined in modern dictionaries. This is deceptive in that it confers arbitrary norms with *sensible* qualities as if they actually stemmed from object properties. Second, it is qualified as *aesthetic*, as if there existed such a category before and beyond its designation. This is deceptive in that it imposes such a category, assuming the existence of special entities susceptible to be sensed and responded to according to individual ability, whilst there are no *aesthetic* properties to which people are more or less apt to respond.

Should we, scientists, keep using *aesthetic* when referring to *hedonic value,* and *sensitivity* when referring to *agreement with standards*? To study compliance with norms, it makes no sense to call it *sensitivity*. To study responsiveness to variations in stimulus properties in sensory valuation, it makes no sense to call it *aesthetic*. Using *sensitivity* to denote individual responsiveness concurs with general definitions of sensitivity—e.g., “the capacity of an organism or sense organ to respond to stimulation” (Merriam–Webster, 2021); “the ability to record small changes in weight, temperature, etc.” and “the quality of being easily influenced or affected by something” (Cambridge, 2021); “the responsiveness of an organ or organism to external stimuli” (Collins, 2021). On the contrary, the term *aesthetic* is inherently deceiving, for this construct, like the idea of god, is not scientifically supported. As Bowman (2006) noted, the epithet *aesthetic* gained considerable currency as a loose synonym for positive or valuable, and *aesthetic sensitivity* became “the *sine qua non* of educational credibility” (p. 1). “The claims to universality, objective neutrality, absolute status and the like served to advance these needs and interests as though they were everyone’s, to silence competing needs and interests, and to bifurcate the world (…) into the genuine (the aesthetically valuable) and an illegitimate, inferior remainder” (p. 3). Thus, “too much is sacrificed for the gain of [the *aesthetic*] label” (Korsmeyer, 2006, p. 8). Indeed, there is no gain when it comes to understanding sensory valuation, but only to perpetuating inequalities and hampering science. Therefore, I suggest, first, discarding *aesthetic*, and second, using *hedonic* to designate the only notion of (aesthetic) sensitivity that is in line with current knowledge and useful to investigate sensory valuation.

In my view, any healthy scientific discipline must regularly revise and rethink its objects of study and the assumptions on which it relies. Namely, we scientists should be aware of and question the origin of the concepts we use, the assumptions implicit in them, their utility, and whether and why we should preserve or discard them (Nadal, 2020). This, for me, is a major challenge in science and philosophy, a necessary goal, and, ultimately, my suggestion in this chapter. Here, I have critically, although succinctly, reviewed and discussed the main aspects of the polymorphic idea of aesthetic sensitivity in psychology. I hope to have exposed some misconceptions and clarified the character and origin of diverse notions of aesthetic sensitivity, their context, functionality, and usefulness.

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IV

Aesthetic Sensitivity in Sensory Valuation

Aesthetic Sensitivity in Sensory Valuation

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Sensory valuation is a basic aspect of animal cognition and crucial for survival. It entails assigning hedonic value to a stimulus based on its sensory properties considering personal and contextual factors. Hedonic values are affective states that motivate behavior according to the pleasure involved, and help implement value-based behavior regulation in the reward system. This involves value mechanisms computing value signals (hedonic values) for wanting, behavioral drive, and liking. We conceive aesthetic sensitivity as the extent to which the computation of hedonic value relies on a particular object feature, thus providing a means to advance the understanding of sensory valuation.

Keywords: sensory valuation, aesthetic appreciation, hedonic value, liking, aesthetic sensitivity

Sensory valuation is a fundamental aspect of cognition (Skov, 2019, 2020). Humans and other animals rely on sensory information to assign value to objects, situations, and events they encounter or anticipate, depending on their current state, goals, and expectations. The ability to judge as desirable or avoidable, liked or disliked, beneficial or damaging enables comparing, deciding, and prioritizing actions (Berridge & Kringelbach, 2013; Pessiglione & Lebreton, 2015; Rangel, Camerer & Montague, 2008). Sensory valuation is, therefore, crucial for survival.

Sensory valuation involves assigning hedonic value to a stimulus based on its sensory properties combined with personal and contextual factors. Hedonic values are responses to projections from sensory systems to distributed nuclei in the reward system, modulated by input from the interoceptive and executive systems—signaling homeostatic state and contextual information relevant to the valuation event (Bartra, McGuire, & Kable, 2013; Becker et al., 2019; Berridge & Kringelbach, 2015; Brown, Gao, Tisdelle, Eickhoff, & Liotti, 2011; Sescousse, Caldú, Segura, & Dreher, 2013; Skov, 2019).

From a functional perspective, hedonic values can be deemed affective states that motivate behavior (Skov, 2020). They do so by spurring the organism to engage in actions involving or eliciting pleasure, and to avoid those entailing or causing displeasure or disgust. In this sense, hedonic values help rewarding or punishing behavioral decisions (Rangel et al., 2008). From a neurobiological perspective, motivated behavior consists of three interrelated, albeit dissociable, phases: an appetitive, a consummatory, and a satiety phase (Berridge & Kringelbach, 2015; Kringelbach & Berridge, 2017; Swanson, 2000). The reward circuit contains different value mechanisms reflecting different aspects of value-based behavior regulation and computing different value signals that help implement these three phases: First, *wanting* mechanisms predict the likely reward of sensory input, informing and promoting approach behavior, biasing perception toward salient features, and modulating neural activity in perceptual and cognitive systems (Berridge, Robinson, & Aldridge, 2009).

Second, another type of value signals contributes to integrating approach and avoidance drives with the brain's executive and motor systems to select and implement behavioral choices (Padoa-Schioppa, 2011; Rushworth, Mars, & Summerfield, 2009). Finally, *liking* mechanisms facilitate the computation of the consummatory phase's outcome: i.e., how rewarding the chosen behavior resulted (Kringelbach & Berridge, 2017). Our conception of aesthetic sensitivity primary focuses on liking mechanisms (Clemente, Pearce, & Nadal, 2021, chapter VIII; Clemente, Skov, Pearce, & Nadal, 2021, chapter IX; Corradi, Chuquichambi, Barrada, Clemente, & Nadal, 2020, chapter V; Corradi et al., 2019), and thus, on the relevance of a particular feature in the computation of this type of hedonic value (see Figure 1).

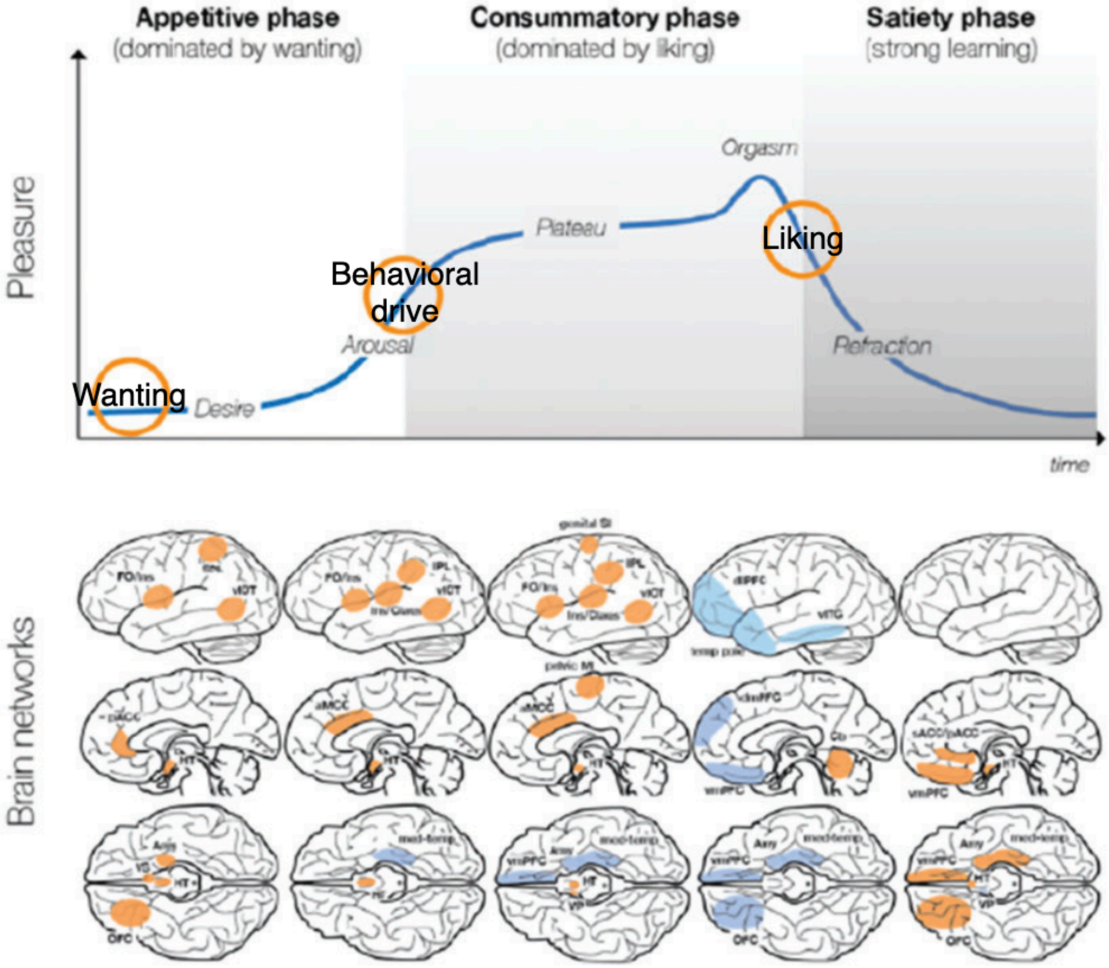

Figure 1. Schematic depiction of the three functional phases and the corresponding value signals characterizing reward processing (adapted from Kringelbach & Berridge, 2017). AMY = amygdala; aMCC = anterior middle cingulate cortex; Claus = claustrum; dlPFC = dorsolateral prefrontal cortex; dmPFC = dorsomedial prefrontal cortex; FO = frontal operculum; HT = hypothalamus; Ins = insula; IPL = intraparietal lobule; med-temp = medial temporal conrtex; OFC = orbitofrontal cortex; pACC = pregenual anterior cingulate cortex; sACC = subgenual anterior cingulate cortex; SPL = superior parietal lobule; temp pole = temporal pole; vlOT = ventrolateral occipitotemporal; vlTG = ventrolateral temporal gyrus; vmPFC = ventromedial proefrontal cortex; VS = ventral striatum.

People assign hedonic values to concrete and biologically relevant objects, such as food and faces (Aharon et al., 2001; Kampe, Frith, Dolan, & Frith, 2001; O'Doherty et al., 2003; Winston, O'Doherty, Kilner, Perrett, & Dolan, 2007), and many kinds of abstract and cultural objects, from money to art (Blood & Zatorre, 2001; Erk, Spitzer, Wunderlich, Galley, & Walter, 2002; Harvey, Kirk, Denfield, & Montague, 2010; Kirk, Harvey, & Montague, 2011). As recently noted by Martin Skov and Marcos Nadal (Nadal & Skov, 2018; Skov, 2019, 2020; Skov & Nadal, 2018, 2019, 2020), aesthetic appreciation is not distinct from sensory valuation. Concurring with the common currency hypothesis (Berridge & Kringelbach, 2015; Levy & Glimcher, 2012; Montague & King-Casas, 2007), aesthetic appreciation must be considered a "fundamental neurobiological phenomenon, yielding elementary hedonic values for cultural objects such as art and music, but also food, sex, social behavior, and economic transactions" (Skov, 2019, p. 240).

Therefore, we use aesthetic appreciation and sensory valuation as synonyms in this research. Whereas *sensory valuation* is, to my understanding, the proper term to designate our ultimate object of study, we use *aesthetic appreciation* or *appreciation* to maintain a connection with previous literature in empirical aesthetics. Thus, the prevalence of one or the other reflects subtle differences in emphasis toward current psychological and neuroscientific knowledge (*sensory valuation*) or prior research in the field (*aesthetic appreciation*).

To understand sensory valuation—i.e., how hedonic value is computed—our principal and framing aim is to investigate the role of object features in aesthetic appreciation. To that end, we proposed a new conception of aesthetic sensitivity, defined as the degree to which a specific feature influences someone's liking, and measure it as the individual slope in linear mixed-effects models (Clemente, Pearce, & Nadal, 2021, chapter VIII; Clemente, Pearce, Skov, & Nadal, 2021, chapter IX; Corradi et al., 2019; Corradi et al., 2020, chapter V). According to this notion, someone who likes complex designs very much but equally dislikes simple ones is highly and positively sensitive to visual complexity. By contrast, a different person may be indifferent to this feature in their liking judgments, that is, aesthetically insensitive to visual complexity. Still, another one may show just the opposite preference (liking more simple images), displaying a high negative sensitivity to visual complexity. Consequently, averaging across people would mask individual sensitivities, thus disregarding personal and contextual factors essential to sensory valuation (see Figure 2). This evinces that merely concluding that people generally like, e.g., complex images hardly contributes to shedding light on the psychological processes driving sensory valuation. In stark contrast, our conception provides a measure of individual variability in sensory valuation, reflecting the extent to which a particular feature contributes to the computation of hedonic value.

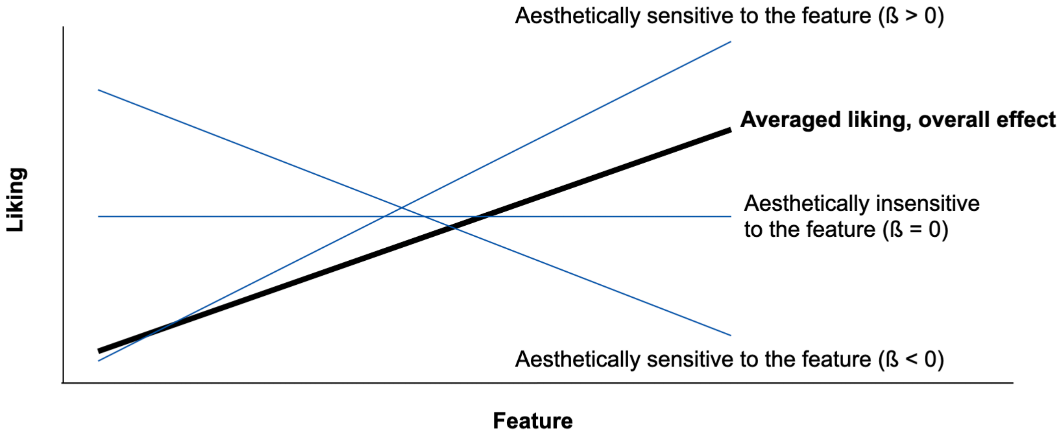

Figure 2. Individual responsiveness or susceptibility to a particular feature in aesthetic appreciation concealed by averaged trends. Blue thin lines represent individual variability in liking ratings for a particular feature, that is, the aesthetic sensitivity to that feature. The thick black line corresponds to mean liking ratings across individuals. ß stands for the individual slope in the model of liking for the particular feature.

In this chapter, I have briefly introduced the neurobiological framework upon which our conception of aesthetic sensitivity rests and to which it contributes. I have also briefly explained and illustrated our notion and measure. The historical and theoretical analyses carried out in these introductory chapters (III and IV) show that, unlike traditional conceptions of aesthetic sensitivity, ours is in line with current knowledge and, at least theoretically, useful to understand aesthetic appreciation (Clemente, Pearce, & Nadal, 2021, chapter VIII; Clemente, Pearce, Skov, & Nadal, 2021, chapter IX; Corradi et al., 2020, chapter V). The research presented in subsequent chapters (V, VIII, IX) tests our conception empirically and uses it to advance the understanding of sensory valuation.

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V

A New Conception of Visual Aesthetic Sensitivity

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A new conception of visual aesthetic sensitivity

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Aesthetic sensitivity has been defined as the ability to recognize and appreciate beauty and compositional excellence, and to judge artistic merit according to standards of aesthetic value. The Visual Aesthetic Sensitivity Test (VAST) has often been used to assess this ability, but recent research has revealed it has several psychometric problems. Such problems are not easily remedied, because they reflect flawed assumptions inherent to the concept of aesthetic sensitivity as traditionally understood, and to the VAST itself. We introduce a new conception of aesthetic sensitivity defined as the extent to which someone's aesthetic valuation is influenced by a given feature. Experiment 1 aimed to characterize aesthetic sensitivity to four prominent features in visual aesthetics: complexity, symmetry, contour, and balance. Experiment 2 aimed to replicate the findings of Experiment 1 and to assess the test–retest reliability of an instrument designed to measure aesthetic sensitivity to these features using an abridged set of stimuli. Our results reveal that people differ remarkably in the extent to which visual features influence their liking, highlighting the crucial role of individual variation when modelling aesthetic preferences. We did not find clear relations between the four measures of aesthetic sensitivity and personality, intelligence, and art interest and knowledge. Finally, our measurement instrument exhibited an adequate-to-good test–retest reliability.

One of the main goals of scientific aesthetics is to explain how people value objects, events, places, and other people. Such explanations often focus on certain sensory features, including symmetry, complexity, or prototypicality (Berlyne, 1971; Fechner, 1876; Martindale, 2001), and are intended to apply to a broad range of situations, people, and objects. They therefore rely on identifying regular response patterns and general perceptual, cognitive, and affective processes (Leder & Nadal, 2014; Pelowski, Markey, Lauring, & Leder, 2016). An example of such explanations is that people prefer symmetry because it facilitates fluent processing, which generates positive subjective feelings (Reber, Schwarz, & Winkielman, 2004).

A complementary goal of scientific aesthetics is to understand how and why some people diverge from general trends (Jacobsen, 2004; Jacobsen & Höfel, 2002). Such divergences have been attributed to the effects of personality (Chamorro-Premuzic,

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Reimers, Hsu, & Ahmetoglu, 2009; Mastandrea, Bartoli, & Bove, 2009; McManus & Furnham, 2006), intelligence (Chamorro-Premuzic & Furnham, 2004; Furnham & Chamorro-Premuzic, 2004), expertise (Belke, Leder, Strobach, & Carbon, 2010; Pang, Nadal, Müller, Rosenberg, & Klein, 2013; Silvia & Barona, 2009), and other personal traits. People differ in their aesthetic valuation because they differ in interests, motivations, capabilities, knowledge, and experience. For instance, art history students prefer asymmetry more than other students, because they rely more on declarative knowledge when making deliberate valuations of visual designs (Leder *et al.*, 2019; Weichselbaum, Leder, & Ansorge, 2018).

The study of individual differences in the appreciation of art and aesthetics began as soon as psychology was applied to education at the turn of the 20th century. Efficient measures of artistic and aesthetic abilities were seen as necessary for testing achievement and for vocational guidance (Burt, 1924, 1933; Meier, 1927, 1928; Thorndike, 1916, 1917). Among such measures, aesthetic sensitivity proved to be the best option for its prognostic value and suitability for laboratory research (Meier, 1928). Meier (1927, 1928) found that aesthetic sensitivity, 'the ability to recognize compositional excellence in representative art-situations, or the ability to "sense" quality (beauty?) in an aesthetic organization' (Meier, 1928, p. 185), was the most efficient and predictive measure of artistic ability.

But how exactly was aesthetic sensitivity conceived? What was thought to determine aesthetic sensitivity? Irving Child (1962, 1965) believed that individual differences in aesthetic sensitivity owed to differences in the extent to which people were familiar with, and accepted, their local tradition of aesthetic evaluation. Child (1962, 1965) argued that aesthetic sensitivity was cultivated with practice and that it was the result of general cognitive style and personality, not of a specific ability. High aesthetic sensitivity, therefore, was the manifestation of an 'actively inquiring mind, seeking out experience that may be challenging because of complexity or novelty, even alert to the potential experience offered by stimuli not already in the focus of attention, interested in understanding each experience thoroughly and for its own sake rather than contemplating it superficially and promptly filing it away in a category, and able to do all this with respect to the world inside himself as well as the world outside' (Child, 1965, p. 508).

Child's views were diametrically opposed to those of the British psychometric tradition, which regarded aesthetic sensitivity as a distinct ability that manifested itself in different tasks. According to Burt (1924, 1933, 1949), this single underlying factor explained performance on different art and aesthetics tests, covering the appreciation of relations among elements in art, among the combinations of lines and colours in painting, and among sounds and words in music and literature. Eysenck (1940, 1941c) believed that this factor, *T*, corresponded to the ability to appreciate objective beauty, that is, people's taste, or aesthetic sensitivity. In Eysenck's view, aesthetic sensitivity was a distinct, general, and stable ability. It was distinct because it was unrelated to other personal traits ('[this ability], independently of intelligence and personality, determines the degree of good or bad taste'; Eysenck, 1983, p. 231), general because it explained performance on virtually all measures of artistic ability ('it covers a large number of, probably all, pictorial tests'; Eysenck, 1940, p. 100), stable because it was biologically determined and innate ('[it] presumably [has] a genetic foundation in the structure of the nervous system'; Götz, Borisy, Lynn, & Eysenck, 1979, p. 801), and insensitive to experience ('[it] is independent of teaching, tradition, and other irrelevant associations'; Eysenck, 1940, p. 102).

Eysenck identified a second factor when the influence of *T* was minimized. This factor, *K*, was bipolar and distinguished 'those who like modern art, bright, sunny photographs, and Kolbe statues, from those who like the older masters, cloudy, foreboding photographs, and the statues of Maillol and Barlach' (Eysenck, 1941c, p. 266). Thus, the main characteristic of the *K* factor is 'one of brightness or intensity as opposed to darkness or lack of intensity' (Eysenck, 1981, p. 91).

T became for art and aesthetics what Spearman's *g* had become for intelligence (Eysenck, 1940, 1941b). If *g* could be scaled and measured, then so could *T*. In Eysenck's (1941a, 1942) view, aesthetic sensitivity scaled as the degree to which liking approximated *true aesthetic value*. True aesthetic value could be estimated by averaging people's preference or by resorting to experts' opinion. Aesthetic sensitivity could thus be calculated by simply subtracting people's average liking ratings from group averages or from experts' judgements. Eysenck used different kinds of materials to measure this notion of aesthetic sensitivity. He first correlated liking ranks of artworks (portraits, drawings, landscapes, statues, and so on) and objects (vases, mathematical functions, flowers, clocks, etc.) with the average rankings (Eysenck, 1940). He later used simple geometric designs (Eysenck, 1972; Eysenck & Castle, 1971) taken from Birkhoff (1932) and the Barron–Welsh Figure Preference Test (Barron & Welsh, 1952). Finally, he developed the Visual Aesthetic Sensitivity Test (VAST) in collaboration with the German artist and designer Karl Otto Götz, who actually produced the stimuli (Chan, Eysenck, & Götz, 1980; Eysenck, 1983; Götz *et al.*, 1979; Iwawaki, Eysenck, & Götz, 1979).

The VAST consists, in its last version (Götz, 1981), of 50 pairs of geometric and artistic designs. Both designs in each pair are very similar, but one of them was argued to be superior to the other in terms of design: 'It is more harmonious, better balanced and better adapted in the way the elements are ordered and in the way the lines are drawn' (Götz, 1981). The task given to the participants is 'to discover which picture has been better designed' (Götz, 1981). In each of the 50 pairs, the correct response had been unanimously selected by a group of 8 painters and graphic artists (Götz, 1981; Götz *et al.*, 1979). The number of correct responses constitutes each person's aesthetic sensitivity score, and a measure of 'the degree of good or bad taste' (Eysenck, 1983, p. 231). One of Eysenck and Götz's main goals in constructing this test was to measure meaningful aesthetic judgements (Eysenck, 1983). This is the reason why it emphasized the role of composition, balance, and harmony.

The VAST was designed intending to overcome the psychometric problems common to earlier design and art judgement tests that presented participants with pairs of correct and incorrect alternatives (e.g., the Graves Design Judgment Test, Graves, 1948; or the Meier–Seashore Art Judgment Test, Meier & Seashore, 1929). The fact is, however, that like the tests it intended to surpass, the VAST exhibits low internal consistency and structural validity, and its scores are explained by intelligence, figural creativity, and personality traits such as conscientiousness, extraversion, or openness to experience (Chamorro-Premuzic & Furnham, 2004; Furnham & Chamorro-Premuzic, 2004; Myszkowski, Çelik, & Storme, 2018; Myszkowski, Storme, Zenasni, & Lubart, 2014). Contrary to Eysenck's (1941a, 1942) claims, thus, this notion of aesthetic sensitivity appears not to be a distinct ability. Rather, it seems to draw upon general cognitive processes, learning, and experience.

Given these problems with the construct of aesthetic sensitivity and the instruments used to measure it, Myszkowski and colleagues (Myszkowski & Storme, 2017; Myszkowski & Zenasni, 2016) suggested two mutually compatible ways forward. One option is to revise the VAST to produce a better instrument. Myszkowski and Storme (2017) introduced an abridged and improved version of the VAST, consisting of 25 items, with better internal consistency and structural validity. The other option is to conceive aesthetic aptitude as a complex of multiple abilities and to turn to a composite measure that includes aesthetic sensitivity (aesthetic balance recognition) together with aesthetic exploration, art expertise, sensitivity to complexity, and aesthetic empathy (Myszkowski & Zenasni, 2016).

Myszkowski and colleagues (Myszkowski & Storme, 2017; Myszkowski & Zenasni, 2016) argued that it is worth holding on to Eysenck's notion of aesthetic sensitivity – or good taste – and revise the VAST because of its usefulness in explaining phenomena (Myszkowski & Storme, 2017). Here, we argue for a different course forward. We believe that there are compelling reasons to doubt the usefulness of Eysenck's construct of aesthetic sensitivity, and the measure provided by the VAST, even in its revised form. Eysenck's construct of aesthetic sensitivity as the appreciation of objective beauty is meaningful and useful only if beauty is truly an objective value; that is to say, it resides in objects themselves, and only if such a value can be determined by averaging laypeople's scores or by expert judgements. There is, however, sufficient evidence to reject both premises.

The first premise is an expression of naïve realism. This is the belief that colour, weight, and sound – and beauty too – are attributes of objects, because through perception and cognition we receive sensory input that gets transformed into percepts and representations that accurately reflect reality (Neisser, 1967; Varela, Thompson, & Rosch, 1991). This belief is refuted by basic facts of perception and cognition. Colour, weight, and sound are not attributes of objects, and neither is beauty. They are attributes of our experience of objects. Phenomena such as colour constancy and simultaneous colour contrast – even the simplest visual illusions – demonstrate that physical properties of reflected light, such as intensity and wavelength composition, do not account for our experience of colour, and of other features (Varela *et al.*, 1991). Perception is not a passive recording of stimuli, and cognition is not about rendering an accurate representation of reality (Neisser, 1967; Singer, 2013). Perception is the active comparing of sensory features with predictions based on global configuration and context (Bar, 2004; Murray, Schrater, & Kersten, 2004; Oliva & Torralba, 2007), knowledge and experience (Alink, Schwiedrzik, Kohler, Singer, & Muckli, 2010; Clark, 2013; Engel, Maye, Kurthen, & König, 2013), and expectations (Egner, Monti, & Summerfield, 2010). And cognition is about making meaning of the world by interacting with it based on what we know and believe about it, what we expect from it, and what we need and want from it (Bruner, 1990).

Beauty, thus, is not an attribute of objects that people are more or less apt at detecting and responding to. Beauty is an attribute of our experience of objects, an experience that is actively constructed by brain systems that seek to make meaning of those objects, their features, and their value to us (Nadal, Gallardo, & Marty, 2017). As in any domain of human experience, when it comes to liking or appreciating beauty, these systems operate on the basis of expectations and predictions (Egermann, Pearce, Wiggins, & McAdams, 2013; Salimpoor, Benovoy, Larcher, Dagher, & Zatorre, 2011), beliefs (Kirk, Skov, Hulme, Christensen, & Zeki, 2009; Locher, Krupinski, & Schaefer, 2015), prior experience (Kirk, Harvey, & Montague, 2011; Kirk, Skov, Christensen, & Nygaard, 2009; Pang *et al.*, 2013), currently available information (Lengger, Fischmeister, Leder, & Bauer, 2007; Mastandrea & Crano, 2019; Swami, 2013), and context (Brieber, Nadal, & Leder, 2015; Gartus & Leder, 2014; Grüner, Specker, & Leder, 2019; Pelowski, Forster, Tinio, Scholl, & Leder, 2017). The notion of aesthetic appreciation as a sort of response to object properties or configurations – a distinct human ability – lingers still in empirical aesthetics. As shown above, however, it runs against a wealth of evidence on the basic functioning of perception and cognition (Skov, 2019). Moreover, it hampers the advance of empirical aesthetics and alienates the field from developments in psychology and neuroscience (Skov & Nadal, 2018).

The second premise, an expression of the belief in immutable aesthetic value, is refuted by historical fact. Many artworks revered by experts and laypeople in their time have faded into oblivion and, conversely, many of the artworks regarded as masterpieces by experts and laypeople today were never admired – some were even rejected – in their time (Pearce *et al.*, 2016). To which experts or laypeople should we turn for the criteria to true aesthetic value? Those in the past? Those in the present? Or those in the future – for that matter? To none, of course. Aesthetic value changes with time and perspective, it is historically and culturally relative (Jacobsen, 2006), and it is, therefore, in no meaningful sense 'true' or inherent. Refuting the notion of objective beauty does not imply, however, that there are no social or cultural beauty norms.

In the absence of objective or true standards of aesthetic value and, therefore, of individual deviations from these standards, it is unclear what phenomena Eysenck's construct of aesthetic sensitivity hopes to account for, and what the VAST actually measures. In order to be meaningful and useful, the construct of aesthetic sensitivity needs to be redefined and brought in line with established psychological and neuroscientific knowledge. A meaningful and useful notion of aesthetic sensitivity should provide information about the different manners in which people construct their aesthetic experiences, and the different extents to which people respond to certain sensory features, and acknowledge the role of experience, knowledge, context, and culture (Che, Sun, Gallardo, & Nadal, 2018; Jacobsen, 2006). The only way forward, thus, is to discard the notion of aesthetic sensitivity as an innate, unalterable, and general ability to appreciate objective beauty, and to accept that the VAST only provides a measure of the ability to discriminate figures according to a specific understanding of harmony (Gear, 1986).

We define aesthetic sensitivity as the extent to which a given feature influences someone's 'aesthetic' valuation, as this regards evaluation of a stimulus using factors typically thought to connect to aesthetic interests – liking, beauty, visual pleasure (Corradi *et al.*, 2019). In this sense, someone is aesthetically sensitive to complexity, for instance, if her aesthetic valuation depends to some degree on objects' complexity: She likes complex designs more than simple ones, or vice versa. Someone is aesthetically insensitive to complexity if this feature is irrelevant to her aesthetic valuation: Her liking is indifferent to complexity. In this sense, aesthetic sensitivity is not equivalent to perceptual sensitivity: It does not gauge whether participants can discriminate fine variations in complexity, for instance. It is also not a measure of receptiveness to artistry – to artful execution or to artistic excellence. Aesthetics and art are, to some extent, overlapping fields, although not identical (Brown & Dissanayake, 2009; Pearce *et al.*, 2016). In the sense put forward here, aesthetic sensitivity is the extent to which certain variations in sensation lead to variations in someone's liking for something (Corradi *et al.*, 2019).

As noted by Corradi *et al.* (2019), this conception of aesthetic sensitivity differs in several regards from Eysenck's (Table 1 summarizes these differences), and has several advantages over Eysenck's. First, it does not rely on the unfounded premise of aesthetic value as an attribute of objects: Here, aesthetic value is an attribute of the experience of objects. Second, there is no external normative standard: Sensitivity is a measure of how responsive someone is to certain features. Third, aesthetic sensitivity is not a unitary construct: It is possible that aesthetic sensitivity is a multidimensional construct. People might be sensitive to some features but not others (Stich, Eisermann, Knäuper, & Leder, 2007). Fourth, aesthetic sensitivity is not a fixed personal trait: It can change depending on

Table 1. Differences between Eysenck's and Corradi and colleagues' conception of aesthetic sensitivity

Eysenck		Corradi *et al.*	
Objectivity	Aesthetic value is an attribute of objects	Aesthetic value is an attribute of our experience of objects	Experience
Standards	There are standards of objective aesthetic value that can be determined	There are no standards of objective aesthetic value to be determined	No standards
Ability	Humans possess the ability to detect objective aesthetic value	Humans construct their experience of objective value	Construction
Singularity	There is a single factor of aesthetic valuation	There are multiple sources for the construction of aesthetic value	Multiplicity
Autonomy	The ability to detect aesthetic value is distinct, unrelated to personality and intelligence	It is probably related to past experience, personality, intelligence, etc.	Relatedness
Context-independent	People's ability to detect aesthetic value is fixed, independently of context	People's aesthetic valuation is context-dependent	Context-dependent

context, experience, expertise, and so on (Leder *et al.*, 2019; Mastandrea & Crano, 2019). Fifth, this notion of aesthetic sensitivity agrees with the common definition of sensitivity as the quality of being receptive to sense impressions, of being responsive to external stimulation. Finally, it is in line with the methods of judgement analysis, or policy capturing (Stewart, 1988), to the domain of aesthetics (Jacobsen, 2004; Jacobsen & Höfel, 2002). These methods model and compare individuals' judgement policies, that is to say, the relations between individuals' judgements and the cues used to make those judgements (Cooksey, 1996; Hammond, Rohrbaugh, Mumpower, & Adelman, 1977; Stewart, 1988).

Our aim in this paper is to explore the construct of aesthetic sensitivity as defined by Corradi *et al.* (2019) and developed in the previous paragraphs. In Experiment 1, we characterize aesthetic sensitivity to four features: complexity, symmetry, contour, and balance. We chose to develop our new concept of aesthetic sensitivity with these four features for two pragmatic reasons. First, they have been extensively studied in empirical aesthetics (e.g., Berlyne, 1971; Bertamini, Palumbo, Gheorghes, & Galatsidas, 2016; Cotter, Silvia, Bertamini, Palumbo, & Vartanian, 2017; Gartus & Leder, 2013; Gómez-Puerto, Munar, & Nadal, 2015; Höfel & Jacobsen, 2003; Jacobsen & Höfel, 2002; Leder *et al.*, 2019; Wilson & Chatterjee, 2005). Second, researchers have developed well-tested stimulus sets to study the effects of these features on aesthetic valuation (Bertamini *et al.*, 2016; Jacobsen & Höfel, 2002; Wilson & Chatterjee, 2005). We also analyse the relations among the aesthetic sensitivities to these features, and to openness to experience, intelligence, art interest and knowledge, and desire for aesthetics, given the evidence that such variables are related to aesthetic appreciation (Chamorro-Premuzic *et al.*, 2009; Furnham & Chamorro-Premuzic, 2004; Furnham & Walker, 2001; Lundy, Schenkel, Akrie, & Walker, 2010; McManus & Furnham, 2006). We chose to analyse our data using linear mixed-effects models. As explained in greater detail below, they are a clear improvement compared to standard multiple regressions commonly used in judgement analysis (e.g., Cooksey, 1996; Stewart, 1988), as they model individual- and group-level responses in combination. In Experiment 2, we conducted a replication of Experiment 1, and studied the temporal stability of aesthetic sensitivities to complexity, symmetry, contour, and balance.

EXPERIMENT 1

Method

Participants

One hundred and sixteen adult students (76 women, $M_{age} = 23.34$ years, $SD_{age} = 5.2$ years) at the University of the Balearic Islands volunteered to participate in the experiment. All participants reported normal or corrected to normal vision. Participants were treated in accordance with the Declaration of Helsinki.

Materials

The materials included three sets of images presented on a computer screen, and three paper-and-pen questionnaires. To obtain measures of aesthetic sensitivity to visual features, we used three sets of stimuli that have been used in previous experiments. To assess aesthetic sensitivity to visual contour, we created 66 patterns following the procedure described by Bertamini *et al.* (2016; Figure 1a). Half of them had curved contours, and the other half had sharp-angled contours. To include some variety in each set, we included stimuli with 22 and 26 vertices, and stimuli with designs based on circles, ovals, and lobed ovals. Curved and sharp-angled sets included the same amount of stimuli with 22 and 26 vertices, and the same amount of stimuli designed from circles, ovals, and lobed ovals. To assess aesthetic sensitivity to visual symmetry and visual complexity, we selected 60 stimuli from Jacobsen and Höfel's (2002) set (Figure 1b). The set contains a

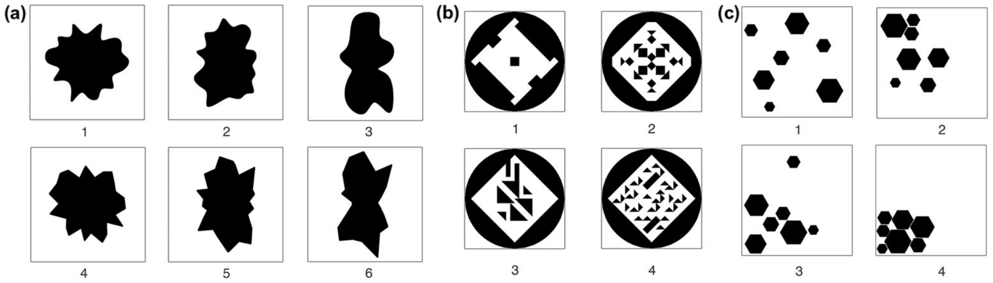

Figure 1. Examples of the stimuli included in the three sets used in Experiments 1 and 2. (a) Examples of stimuli used to assess aesthetic sensitivity to contour. They were designed following Bertamini *et al.* (2016). Stimuli on the top row (A1 to A3) have curved contours; stimuli on the bottom row are equivalent but have sharp-angled contours. Stimuli A1 and A4 were designed based on circles, A2 and A5 on ovals, and A3 and A6 on lobed ovals. (b) Examples of stimuli used to assess aesthetic sensitivity to complexity and symmetry, from Jacobsen and Höfel's (2002) set. Stimuli on the top row (B1 and B2) are symmetrical; stimuli on the bottom row (B3 and B4) are asymmetrical. Stimuli on the left (B1 and B3) are simpler than stimuli on the right (B2 and B4). (c) Examples of stimuli used to assess aesthetic sensitivity to balance, from Wilson and Chatterjee's (2005) set. Stimuli from C1 to C4 cover the range from balanced to unbalanced.

series of images of solid black circles with a centred white square containing triangles that are combined to form designs of varying complexity and symmetry. We used 30 symmetrical and 30 asymmetrical stimuli. Each of these categories included stimuli matched for different degrees of complexity, corresponding to the amount of constituting elements. To assess aesthetic sensitivity to visual balance, we used Wilson and Chatterjee's (2005) set of 65 stimuli consisting of diverse configurations of hexagons (Figure 1c). These stimuli were created to vary in balance, measured as the average of eight symmetry components over the axes of the stimuli. Each stimulus has a corresponding measure of objective balance.

All stimuli in all sets were black and white figures displayed on a medium grey background. Image sizes were 450 pixels on a 1,920 × 1,080 computer screen sized 21", and participants were placed at approximately 45 centimetres of the screen.

After completing the aesthetic sensitivity task, participants filled out three paper-and-pen questionnaires. The first was a custom experience and knowledge in visual art questionnaire adapted from Chatterjee, Widick, Sternschein, Smith, and Bromberger (2010). Five of the items asked about interest in art (1) How interested are you in art? (2) How often do you visit art museums or galleries? (3) How often do you look at art magazines or catalogues? (4) How often do you look at art on the Internet? (5) How often do you speak about art with friends or family?, and three asked about formal education in art (6) How many art history courses did you take during or after high school? (7) How many art creation courses did you take during and after high school? (8) How many hours on average do you spend creating visual art?. Participants were asked to answer each question on a 0–6 Likert scale, where 0 corresponded to *Nothing at all* (1), *Never* (2–5), or *None* (6–8), and 6 corresponded to *Very much* (1), *Once a week* (2), *Very frequently* (3–5), or *6 or more* (6–8). The second questionnaire consisted of the 12 items of the openness to experience scale of the NEO-FFI (McCrae & Costa, 2004). Finally, participants completed an abridged version of Raven's SPM (Raven, 1938; Seisdedos, 1996). We selected 26 items based on responses by a different sample of 150 respondents taken from the same population. We selected those items with at least one error in the previous experiment responses. This reduction aimed to make the whole session shorter.

Procedure

Participants undertook the experimental procedure at the psychology laboratory. They were first welcomed to the laboratory and briefed about the entire procedure. Each participant was then asked to enter one of the individual testing cabins, all of which have the same kind of computers, software, and light conditions. In the testing cabin, participants received the same standard spoken and onscreen instructions. They were told that they would be seeing images on the computer screen and that they had to rate each of them according to how much they liked them. They were instructed to use the keyboard to answer on a 1–7 Likert scale, where 1 meant 'I don't like it at all', and 7 meant 'I like it a lot'. Each stimulus was presented in the centre of the screen. Below the stimulus there was a reminder of the scale, tagged from 1 to 7. Each response was followed by a 2-s grey screen before the next trial started. The task was divided into three blocks: contour, balance, and symmetry–complexity. The order of the blocks and the order of stimuli within each block were randomized for each participant.

Data analysis

Participants' responses to stimuli in each block were analysed by means of linear mixed-effects models (Hox, 2010; Snijders & Bosker, 2012). Linear mixed-effects models account simultaneously for the between-subjects and within-subjects effects of the independent variables (Baayen, Davidson, & Bates, 2008), unlike ANOVAs. ANOVAs usually require averaging across stimuli, which can cause the empirical type I error rate to greatly exceed the nominal level, and lead to claims of significant effects that are unlikely to replicate with different samples (Judd, Westfall, & Kenny, 2012, 2017). As pointed out by Nezlek (2001), linear mixed-effects models provide the most accurate analyses of hierarchically structured data in which there is some kind of dependency, which is the case here, where responses to stimuli are dependent on, or nested within, individual participants. This is because they model random error at all levels of analysis simultaneously, relying on maximum likelihood procedures to estimate coefficients. Linear mixed-effects models have other additional advantages, even over multiple regression analyses (Hox, 2010; Snijders & Bosker, 2012): They provide meaningful estimates of subject- and group-level variance components and are able to handle incomplete and unbalanced data, to accommodate continuous and categorical predictors, unbiased handling of outliers, widespread availability, flexibility, and ease of use (Judd *et al.*, 2012). One particularly interesting feature is that they make it possible to derive conclusions that generalize to other participants besides the ones providing the data (Judd *et al.*, 2017; Nezlek, 2001). Linear mixed-effects models are, thus, well suited to analyse preference responses, given that these often vary from one person to another and also from one objet to another (Silvia, 2007). For this reason they have been used successfully in experimental aesthetics (Brieber, Nadal, Leder, & Rosenberg, 2014; Cattaneo *et al.*, 2015; Mühlenbeck, Jacobsen, Pritsch, & Liebal, 2017; Mühlenbeck, Liebal, Pritsch, & Jacobsen, 2015, 2016; Vartanian *et al.*, 2019; Wagner, Menninghaus, Hanich, & Jacobsen, 2014). They are especially well suited to the purposes of the current study, because they provide estimates for group-level effects, which can be compared with previous studies, and estimates for participant-level effects, which constitute our measure of individual aesthetic sensitivity.

In the present study, the models were set up to reflect the effect of the main predictors in each set on participants' responses. In all cases we followed Barr, Levy, Scheepers, and Tily's (2013) suggestion to model the maximal random-effects structure justified by the experimental design. This avoids the loss of power, reduces type I error, and enables the generalizability of results to other participants and stimuli. All analyses were carried out within the R environment for statistical computing, version 3.5.0. (R Core Team, 2018), using the *glmer()* functions of the 'lme4' package, version 1.1-18-1 (Bates *et al.*, 2017), fitted with REML estimation. The 'lmerTest' package, version 3.0-1 (Kuznetsova, Brockho, & Christensen, 2012), was used to estimate the *p*-values for the *t*-tests based on the Satterthwaite approximation for degrees of freedom, which produces acceptable type I error rates (Luke, 2017).

The model of liking for contour included the interaction between contour (*curved*, *sharp-angled*), shape (*circle*, *oval*, *lobed oval*), and vertices (*22*, *26*) as fixed effects. It also included the slope for each of these features and their interactions as random effects within participants. The model of liking for symmetry (*symmetricalal*, *asymmetrical*) and complexity (*number of elements*) included the interaction between both features. It also included the slope for both of these features and their interaction as random effects within participants. The model of liking for balance included balance (*objective balance index*) as a fixed effect. It also included the slope for balance as a random effect within participants. All models also included random intercepts within stimuli. In all models, categorical predictors were deviation coded. Continuous predictors were centred and, to allow comparison with categorical variables, they were scaled from −0.5 to 0.5. Reference levels for the categorical variables were: ***sharp***, ***lobed oval***, ***22***, and ***asymmetrical***.

Although the models described above produce group estimates, the main aim of this study was to understand individual differences in responsiveness to visual features driving aesthetic preference. In the linear mixed-effects models, this corresponds to the modelled individual slope for each of the four features: contour, symmetry, complexity, and balance. We thus define each participant's aesthetic sensitivity to each of these features as the individual slope estimated from the models' random-effect structure. Therefore, after running each model, we extracted each participant's slopes and used these values to describe aesthetic sensitivity to visual contour, symmetry, complexity, and balance, to explore the relations among them, and to determine whether aesthetic sensitivity to any of these features was explained by art interest, art knowledge, intelligence, or openness to experience.

Results

Contour

The results of the liking for contour model showed that overall, participants liked the curved images (m = 3.86 [3.66, 4.07]) more than the sharp-angled images (m = 2.75 [2.54, 2.96]), $\beta = 1.11$, $t_{(141,57)} = 9.182$, $p < .001$ (Figure 2a). Participants also liked the figures based on lobed ovals (m = 3.42 [3.22, 3.63]) more than the circles (m = 3.20 [3.01, 3.38]), $\beta = 0.12$, $t_{(87,26)} = 2.552$, $p = .013$, and the ovals (m = 3.29 [3.11, 3.48]), $\beta = 0.11$, $t_{(88,15)} = 2.294$, $p = .024$. Participants' liking ratings did not differ for figures with 22 vertices (m = 3.29 [3.12, 3.47]) and for figures with 26 vertices (m = 3.32 [3.13, 3.50]), $\beta = -0.012$, $t_{(51,49)} = 0.441$, $p = .661$.

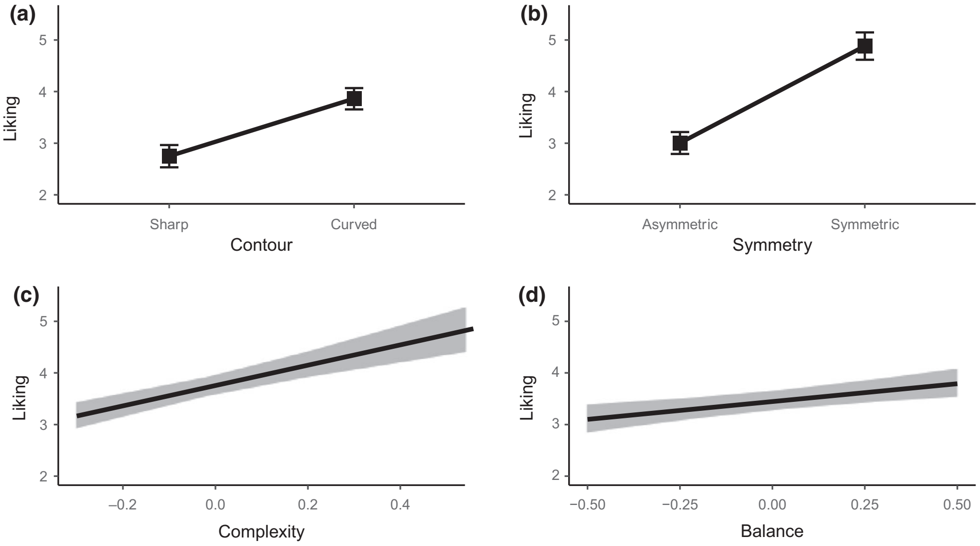

Figure 2. Main effects of contour (a), symmetry (b), complexity (c), and balance (d) on participants' liking ratings in Experiment 1.

Variation among participants in the effects of contour represented 57.47% of the model's explained variance. Removal of the random slope for contour within participants significantly reduced the model fit, $\chi^2 = 1415.8$, $df = 5$, $p < .001$. The estimated slopes for participant's liking for curved contours ranged from -1.41 (indicating higher liking for sharp-angled contours) to 4.48 (indicating higher liking for curved contours), with a mean of 1.11 and a standard deviation of 1.14 (Figure 3a). The values corresponding to the first, second, and third quartiles were 0.36, 1.05, and 1.81.

Symmetry and complexity

The model of liking for symmetry and complexity revealed that participants liked the symmetrical images ($m = 4.88$ [4.62, 5.15]) more than the asymmetrical images ($m = 3.00$ [2.79, 3.22]), $\beta = 1.88$, $t_{(130,88)} = 12.610$, $p < .001$ (Figure 2b). Participants' liking increased with complexity, $\beta = 2.13$, $t_{(78,45)} = 5.476$, $p < .001$ (Figure 2c). The interaction between complexity and symmetry was significant, indicating that the effects of complexity on liking were stronger for symmetrical stimuli than for asymmetrical stimuli, $\beta = 1.64$, $t_{(63,94)} = 2.229$, $p = .029$.

Variation among participants in the effects of symmetry represented 12.08% of the model's explained variance. Removal of the random slope for symmetry within participants significantly reduced the model fit, $\chi^2 = 885.83$, $df = 7$, $p < .001$. The estimated slopes for participant's liking for symmetry ranged from -1.36 (indicating greater liking for asymmetrical designs) to 4.07 (indicating greater liking for symmetrical designs), with a mean of 1.88 and a standard deviation of 1.02 (Figure 3b). The values corresponding to the first, second, and third quartiles were 1.18, 1.92, and 2.60.

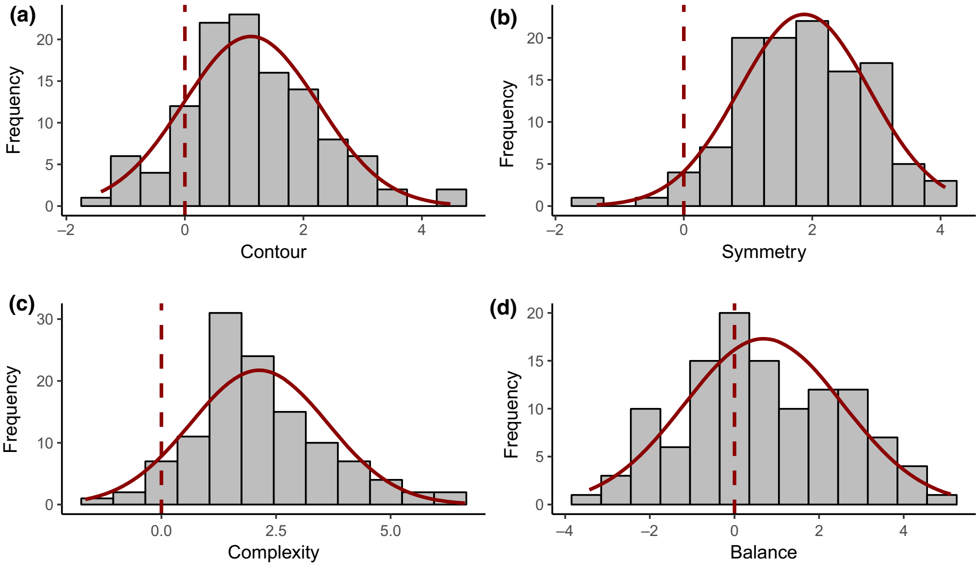

Figure 3. Histograms of individual slopes of liking for contour (a), symmetry (b), complexity (c), and balance (d) in Experiment 1. Vertical dashed lines correspond to a slope of 0, meaning absolute indifference towards each feature. Positive slopes indicate higher liking for curved, symmetrical, complex, and balanced stimuli. Negative slopes indicate higher liking for sharp-angled, asymmetrical, simple, and unbalanced stimuli. Normal curves are overlaid in dark red. [Colour figure can be viewed at wileyonlinelibrary.com]

Variation among participants in the effects of complexity represented 32.22% of the model's explained variance. Removal of the random slope for complexity within participants significantly reduced the model fit, $\chi^2 = 194.7$, $df = 7$, $p < .001$. The estimated slopes for participant's liking for complexity ranged from −1.66 (indicating greater liking for simple designs) to 6.62 (indicating greater liking for complex designs), with a mean of 2.13 and a standard deviation of 1.49 (Figure 3c). The values corresponding to the first, second, and third quartiles were 1.18, 2.01, and 2.97.

Balance

The model of liking for balance showed that participants' liking ratings increased with balance, $\beta = 0.691$, $t_{(145,52)} = 3.454, p < .001$ (Figure 2d). Variation among participants in the effects of balance represented 78.97% of the model's explained variance. Removal of the random slope for balance within participants significantly reduced the model fit, $\chi^2 = 1396.2.7$, $df = 2, p < .001$. The estimated slopes for participant's liking for balance ranged from −3.43 (indicating greater liking for unbalanced configurations) to 5.11 (indicating greater liking for balanced configurations), with a mean of 0.69 and a standard deviation of 1.87 (Figure 3d). The values corresponding to the first, second, and third quartiles were −0.52, 0.64, and 1.98.

Correlations among individual liking slopes

To determine whether there were any relations among individual liking slopes, we studied the correlations among them. The results of this analysis revealed that aesthetic sensitivity to balance was uncorrelated with aesthetic sensitivity to the rest of the features (Table 2). Aesthetic sensitivity to contour and to complexity correlated significantly, and so did aesthetic sensitivity to complexity and to symmetry. Thus, participants who liked complex stimuli also tended to like symmetrical stimuli and stimuli with curved contours.

Explaining aesthetic sensitivity

We ran one regression analysis for each feature to determine whether openness to experience, intelligence, and art interest and knowledge accounted for differences in aesthetic sensitivity among participants. Table 3 shows that art knowledge predicted aesthetic sensitivity to contour, and art interest predicted aesthetic sensitivity to symmetry. In both cases, the relation was negative, indicating that participants who declared having more knowledge of art were those who were less sensitive to contour and

Table 2. Correlations among individual slopes for contour, symmetry, complexity, and balance in Experiment 1

Feature	Contour	Symmetry	Complexity	Balance
Contour	–			
Symmetry	.17	–		
Complexity	.23*	.24**	–	
Balance	.04	.00	.07	–

Note. Spearman correlations for 116 participants.
*$p < .05$; **$p < .01$.

that participants who declared being more interested in art were those who were less sensitive to symmetry (Figure 4). Neither openness to experience nor intelligence significantly predicted aesthetic sensitivity to any of the attributes.

Discussion

The main aim of this study was to introduce a new conception of aesthetic sensitivity in the visual domain. This new conception defines aesthetic sensitivity as the degree to which a person's aesthetic valuation is influenced by a certain sensory feature. The goal of Experiment 1 was to measure and characterize aesthetic sensitivity to four features that have been studied extensively: contour, symmetry, complexity, and balance. We modelled aesthetic sensitivity as the individual slopes of the effects of each of these features on participants' liking.

At a group level, our results support previous findings on the effects of contour, symmetry, complexity, and balance on liking. People tend to like designs with curved contours that are symmetrical, complex, and balanced more than those with sharp-angled contours, and those that are asymmetrical, simple, and unbalanced (Gómez-Puerto *et al.*, 2015, 2018; Höfel & Jacobsen, 2003; Jacobsen & Höfel, 2002; Wilson &

Table 3. Regression coefficients in Experiment 1

	Openness	Intelligence	Art interest	Art knowledge
Contour	0.035	−0.038	−0.002	−0.099*
Symmetry	0.015	−0.014	−0.053**	0.033
Complexity	−0.008	−0.016	−0.034	−0.040
Balance	−0.009	0.046	0.014	−0.090

Note. Regression coefficients for each of the four predictors based on data from 116 participants.
*$p < .05$; **$p < .01$.

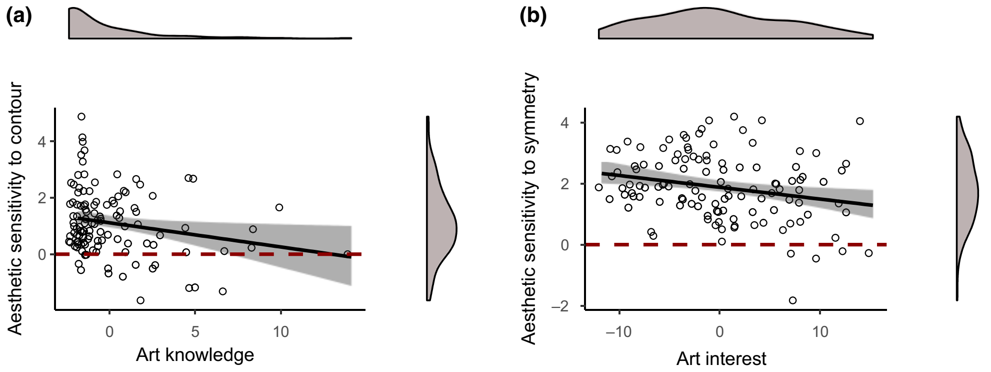

Figure 4. Aesthetic sensitivity to contour and aesthetic sensitivity to symmetry predicted by art knowledge and art interest (Experiment 1). Art knowledge predicts aesthetic sensitivity to contour (a), and art interest predicts aesthetic sensitivity to symmetry (b). The figure includes density plots (top) of art knowledge and art interest, and density plots (right) of aesthetic sensitivity to contour and symmetry. Horizontal dashed lines mark the level of aesthetic indifference to each feature. [Colour figure can be viewed at wileyonlinelibrary.com]

Chatterjee, 2005). This confirmation is, in itself, a meaningful finding. With very few exceptions (Cotter *et al.*, 2017; Gartus & Leder, 2013, 2017; Silvia, 2007), the effects of these features on liking have previously been analysed using ANOVAs or *t*-tests. We have confirmed that these effects hold when data are analysed using linear mixed-effects models, that is to say, when within- and between-participants variations are accounted for.

Our results on aesthetic sensitivity reveal that although the general trend is to like curved contours, symmetrical, complex, and balanced designs, people vary in the extent to which such features influence their liking. Differences among participants in the extent to which each of those features influenced their liking corresponded to large percentages of the variance explained by the models. In all cases, the inclusion of the random slope for the features within participants produced a much better fit to the data. It can be concluded, thus, that attending only to the general trends in liking for curved contours, symmetry, complexity, and balance overlooks a considerable variation in the extent to which such features influence individuals' liking (Jacobsen, 2004; Jacobsen & Höfel, 2002).

Given Eysenck's claim for a single factor underlying aesthetic sensitivity, we were interested in the relations among the aesthetic sensitivity scores we obtained for each of the four features. Our correlation analysis revealed that aesthetic sensitivity to the four features were either unrelated to each other or only modestly related. This suggests that as a rule, people who are highly sensitive to one feature are not necessarily sensitive to another. There were, however, modest relations between complexity and contour, and between complexity and symmetry, indicating that to some extent people who prefer complex stimuli also prefer symmetrical and curved-contour stimuli.

We were also unable to find consistent relations between aesthetic sensitivity and personality, intelligence, and art interest or knowledge. None of the measures of aesthetic sensitivity were predicted by openness to experience or intelligence. We did find a negative relation between art knowledge and aesthetic sensitivity to contour, and a negative relation between art interest and aesthetic sensitivity to symmetry, suggesting that the more knowledge and interest in art, the less people's liking is affected by these features. However, given that our sample was composed mostly of people with very little art knowledge, such conclusions need to be treated with caution.

Experiment 2 had two goals. The main goal was to ascertain the test–retest reliability of an abridged set of stimuli assessing aesthetic sensitivity to contour, symmetry, complexity, and balance. We hoped to produce an abridged version of our materials that would be less time-consuming in experiments, and still be suitable. We thus asked a new group of participants to take part in a test–retest procedure. The second goal was to replicate our findings in Experiment 1, and the test phase of Experiment 2 served this goal.

EXPERIMENT 2

Method

Participants

Participants were 91 students (M_{age} = 26.17 years, SD_{age} = 7.33 years, 45 men, all adults) attending the University of the Balearic Islands. All participants reported normal or corrected to normal vision and had not participated in the Experiment 1. The study was conducted in accordance with the Declaration of Helsinki.

Materials

Hoping to develop a more time-efficient measure of aesthetic sensitivity, we reduced the number of items participants were asked to rate. To assess aesthetic sensitivity to visual contour, we selected 24 stimuli from those used in Experiment 1. Half of these had curved contours and half had sharp angles. In each subset, we included the same number of shapes created from circles, ovals, and lobed ovals, and the same number of shapes with 22 and 26 vertices. To assess aesthetic sensitivity to complexity and symmetry, we took 20 items from our previous selection of Jacobsen and Höfel (2002) set, 10 of which were symmetrical and 10 asymmetrical. Both subsets included the same variation in complexity. To assess aesthetic sensitivity to balance, we took 22 stimuli from Wilson and Chatterjee's (2005) stimulus set, which were equally spaced in terms of balance scores. Participants completed the same art interest and activities questionnaire as in Experiment 1, the 12 items of the openness to experience scale of the NEO-FFI (McCrae & Costa, 2004), and an abridged, adapted, and translated version of the Desire for Aesthetics Scale (DAS) (Lundy *et al.*, 2010). Our adapted version of the DAS consisted of 9 items, rated on a 0 (*I completely disagree*)-to-6 (*I completely agree*) scale: (1) When I see beautiful things in daily life I rarely feel passionate about them. (2) One of the reasons I love travelling is seeing gorgeous scenery. (3) When watching a movie or series I enjoy noticing visual details (photography, framing, colours, . . .). (4) I enjoy spending time appreciating architecture. (5) I often find myself staring in awe at beautiful things. (6) I notice the details of brand logos. (7) I notice and care about design. (8) I notice and attend to the details in paintings, architecture, sculpture, and graphic work. (9) The details I notice in paintings, architecture, sculpture, and graphic art evoke emotions in me.

Procedure

The task was the same as described in Experiment 1, but it took participants less time to complete, as this abridged version contained approximately one third of the items. Participants performed the task in identical conditions as in Experiment 1, except that they performed it twice, with 14 days between the test and retest sessions. They completed the paper-and-pen questionnaires only in the test session.

Data analyses

All analyses were performed as described in Experiment 1. The exception is the new test–retest analysis. In order to examine the temporal stability of the aesthetic sensitivity measure, we conducted an analysis based on Bland and Altman's (1986) graphical method and the smallest real difference (SRD), a measure of absolute reliability (Vaz, Falkmer, Passmore, Parsons, & Andreou, 2013). Bland and Altman's (2003) graphical method has the advantage that it is unaffected by the variability in the data, as it is based upon the SRD (Vaz *et al.*, 2013), and that it can detect systematic biases in the test–retest procedure. It is based on the mean difference between each participant's scores on the test and retest phases. This method establishes the limits of agreement at 1.96 times the standard deviation above and below this difference. When this interval contains the value 0, the difference between the two measurements could be attributed to error (Beckerman *et al.*, 2001). When it does not, the difference must be attributed to some systematic bias. Bland and Altman's (1986) graphs plot the differences between the test and retest scores against the average, allowing the identification of cases where differences in the measurement are proportional to the measurement magnitude. There is no way to determine whether the limits of agreement for the difference on a given test–retest measure are wide or small. The method merely establishes the boundaries of the minimal detectable true change (Vaz *et al.*, 2013).

Results

Contour

Participants liked the curved-contour images (m = 3.80, [3.48, 4.13]) more than the sharp-angled ones (m = 2.86, [2.47, 3.16]), $\beta = 0.94$, $t_{(28,23)} = 5.11$, $p < .001$ (Figure 5a). There were no differences among participants' liking for stimuli based on lobed ovals (m = 3.44 [3.11, 3.77]), circles (m = 3.29 [2.96, 3.63]), or ovals (m = 3.26 [2.93, 3.60]) (all ps > .354). Liking did not differ for stimuli with 22 (m = 3.33 [3.03, 3.62]) and 26 (m = 3.34 [3.05, 3.63]) vertices either (p = .943).

Variation among participants in the effects of contour on liking ratings represented 50.37% of the model's explained variance. Removal of the random slope for contour within participants from the model significantly reduced the model fit, $\chi^2 = 248.23$, $df = 5, p < .001$. The estimated slopes for participants' liking for curved contours ranged from −2.24 (indicating greater liking for sharp-angled contours) to 3.14 (indicating greater liking for curved contours), with a mean of 0.94 and a standard deviation of 0.96 (Figure 6a). The values corresponding to the first, second, and third quartiles were 0.23, 0.87, and 1.54.

Symmetry and complexity

Participants liked the symmetrical designs (m = 4.68 [4.40, 4.96]) more than the asymmetrical ones (m = 3.70 [3.39, 4.02]), $\beta = 0.97$, $t_{(42,02)} = 6.457$, $p < .001$

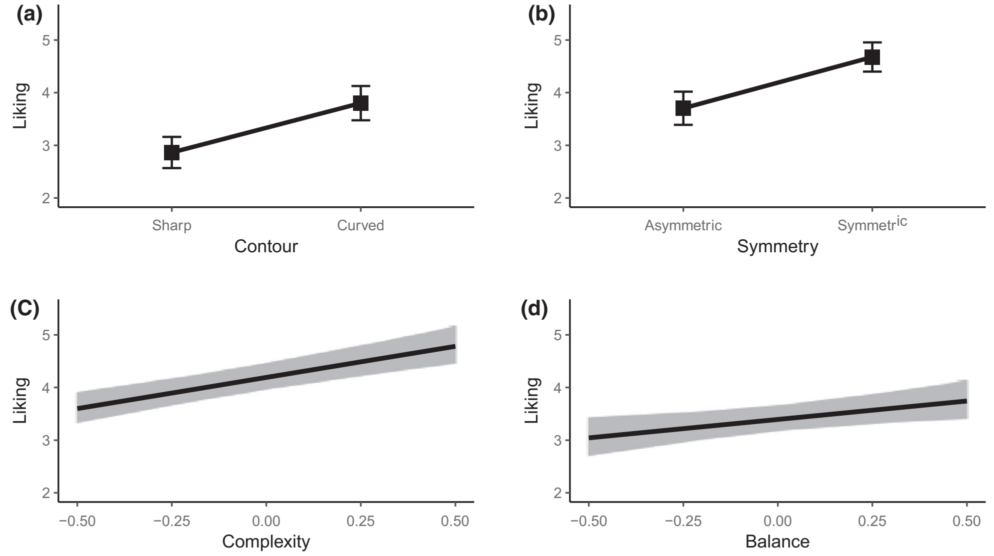

Figure 5. Main effects of contour (a), symmetry (b), complexity (c), and balance (d) on participants' liking ratings during the test phase of Experiment 2.

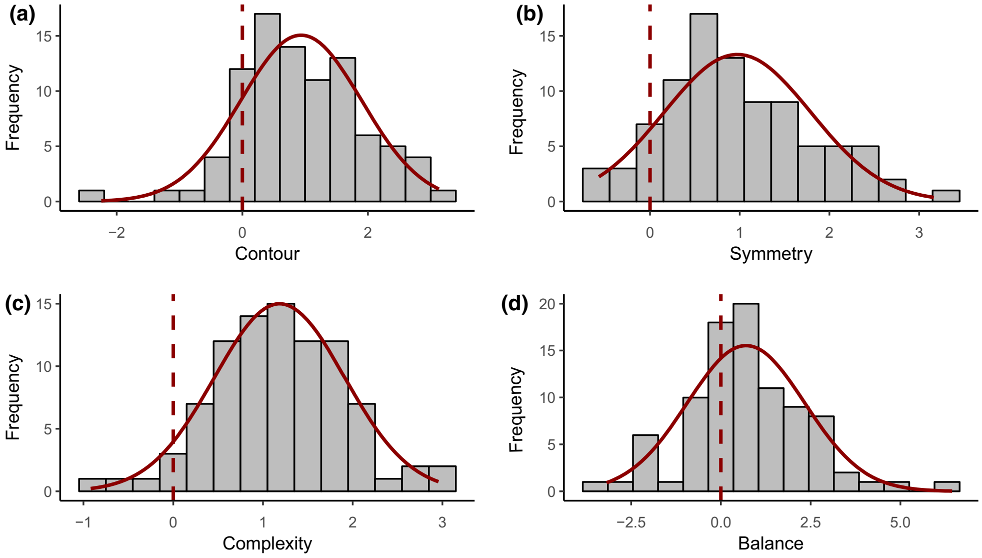

Figure 6. Histograms of individual slopes of liking for contour (a), symmetry (b), complexity (c), and balance (d) during the test phase of Experiment 2. Vertical dashed lines correspond to a slope of 0, meaning absolute indifference towards each feature. Positive slopes indicate higher liking for curved, symmetrical, complex, and balanced stimuli. Negative slopes indicate higher liking for sharp-angled, asymmetrical, simple, and unbalanced stimuli. Normal curves are overlaid in dark red. All data are from the test phase of Experiment 2. [Colour figure can be viewed at wileyonlinelibrary.com]

(Figure 5b). Participants' liking increased with complexity, $\beta = 1.185$, $t_{(26.25)} = 5.849$, $p < .001$ (Figure 5c). The interaction between complexity and symmetry was not significant, $\beta = 0.726$, $t_{(18.86)} = 1.970$, $p = .064$.

Variation among participants in the effects of symmetry on liking ratings represented 21.90% of the model's explained variance. Removal of the random slope for symmetry within participants from the model significantly reduced the model fit, $\chi^2 = 132.68$, $df = 7$, $p < .001$. The estimated slopes for participant's liking for symmetry ranged from −0.57 (indicating greater liking for asymmetrical designs) to 3.16 (indicating greater liking for symmetrical designs), with a mean of 0.97 and a standard deviation of 0.82 (Figure 6b). The values corresponding to the first, second, and third quartiles were 0.41, 0.83, and 1.46.

Variation among participants in the effects of complexity on liking ratings represented 21.93% of the model's explained variance. Removal of the random slope for complexity within participants from the model significantly reduced the model fit, $\chi^2 = 63.40$, $df = 7$, $p < .001$. The estimated slopes for participant's liking for complexity ranged from −0.92 (indicating greater liking for simple designs) to 2.96 (indicating greater liking for complex designs), with a mean of 1.19, standard deviation of 0.73 (Figure 6c). The values corresponding to the first, second, and third quartiles were 0.73, 1.17, and 1.67.

Balance

Participants' liking ratings increased with balance, $\beta = 0.70$, $t_{(57.57)} = 2.539$, $p = .014$ (Figure 5d). Variation among participants in the effects of balance on liking ratings represented 73.97% of the model's explained variance. Removal of the random slope for balance within participants from the model significantly reduced the model fit, $\chi^2 = 208.72$, $df = 2$, $p < .001$. The estimated slopes for participant's liking for balance ranged from −3.18 (indicating greater liking for unbalanced configurations) to 6.44 (indicating greater liking for balanced configurations), with a mean of 0.70 and a standard deviation of 1.64 (Figure 6d). The values corresponding to the first, second, and third quartiles were −0.24, 0.66, and 1.65.

Correlations among individual liking slopes

To determine the relations among individual liking slopes, we studied the correlations among them. The results of this analysis revealed that the only two features for which individual preference slopes correlated were contour and complexity, indicating that participants who were aesthetically sensitive to contour were also aesthetically sensitive to complexity (Table 4).

Explaining aesthetic sensitivity

We ran four regressions to determine whether openness to experience, desire for aesthetics, and art interest and knowledge explained differences among participants in aesthetic sensitivity to each of the features. These variables explained only aesthetic sensitivity to balance. Table 5 shows that art knowledge negatively predicted aesthetic sensitivity to balance ($\beta = -0.401$, $t = 2.11$, $p = .038$): Those who declared having more art knowledge were less susceptible to the effects of balance. Openness to experience, desire for aesthetics, and art interest had no significant effect on aesthetic sensitivity to any of the four attributes.

Table 4. Correlations between individual liking slopes for contour, symmetry, complexity, and balance in the test phase of Experiment 2

Feature	Contour	Symmetry	Complexity	Balance
Contour	–			
Symmetry	.07	–		
Complexity	.23*	−.07	–	
Balance	.08	.12	.08	–

Note. Spearman correlations for 91 participants.
$^*p < .05$.

Table 5. Regression coefficients in Experiment 2

	Openness	Desire for aesthetics	Art interest	Art knowledge
Contour	0.007	0.012	−0.048	0.047
Symmetry	0.009	0.016	0.048	−0.116
Complexity	0.006	−0.002	0.106	−0.139
Balance	−0.052	0.052	0.280	−0.401*

Note. Regression coefficients for each of the four predictors based on data from 91 participants.
$^*p < .05$.

Test–retest reliability

Table 6 shows the results of the analyses based on the smallest real difference (SRD), the absolute measure of test–retest reliability, and Figure 7 shows the corresponding Bland–Altman graphs. These analyses revealed that whereas the test–retest differences in the assessment of aesthetic sensitivity to contour and balance can be attributed to random error, this is not the case with the assessment of aesthetic sensitivity to symmetry and complexity. In both of these cases there is a systematic bias in the differences. In the case of symmetry, participants were more sensitive in the retest phase. In the case of complexity, participants were less sensitive in the retest phase. Such differences,

Table 6. Mean difference and smallest real difference measures of test–retest reliability of aesthetic sensitivity to contour, symmetry, complexity, and balance in Experiment 2

		95% CI		
Feature	Mean retest–test difference	Lower	Upper	Smallest real difference
Contour	−0.063	−0.253	0.127	1.693
Symmetry	0.237	0.071	0.402	1.474
Complexity	−0.289	−0.501	−0.076	1.898
Balance	0.144	−0.290	0.578	3.870

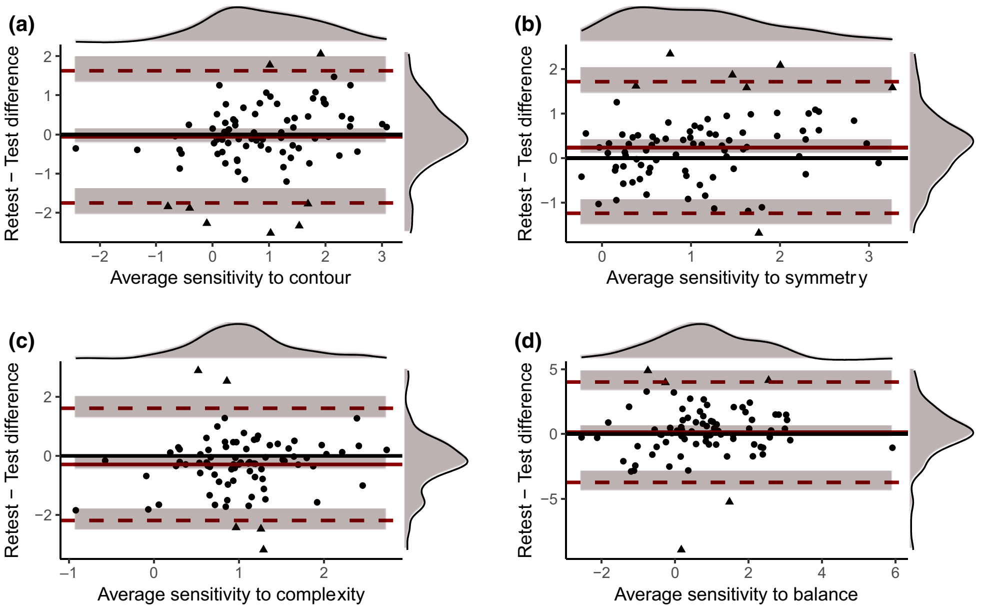

Figure 7. Bland–Altman graphs for the test–retest reliability of aesthetic sensitivity to contour (a), symmetry (b), complexity (c), and balance (d). Horizontal black lines indicate no retest–test change. Horizontal continuous red lines indicate the mean retest–test difference. Horizontal dashed lines mark the lower and higher limits of agreement. Horizontal ribbons comprise 95% CI. Circles correspond to participants whose retest–test difference is smaller than the smallest real difference (SRD). Triangles correspond to participants whose retest–test difference is larger than the SRD. [Colour figure can be viewed at wileyonlinelibrary.com]

however, can be attributed to very few participants. In the case of symmetry, seven participants exceeded the SRD: Six (6.6%) got higher scores in the retest phase and one (1.1%) in the test phase. In the case of complexity, five participants (5.5%) exceed the SRD. Three got lower scores in the retest phase, and 2 (2.2%), much higher scores in the retest phase. Only four participants exceeded the SRD for two of the features. No participant exceeded the SRD for more than two features.

Discussion

Experiment 2 had two goals. On the one hand, we wished to determine whether the results of Experiment 1 would replicate with a new sample of participants. On the other, we wished to examine the temporal stability of a computerized assessment of aesthetic sensitivity to contour, symmetry, complexity, and balance. The results of Experiment 2 replicate the results of Experiment 1, but they also suggest that our abridged assessment has an adequate test–retest reliability.

The results of Experiment 1 and Experiment 2 are remarkably similar. At the group level, participants in both experiments liked the curved-contour stimuli more than the sharp-angled ones, the symmetrical stimuli more than the asymmetrical ones, and liking increased with complexity and balance. In the case of contour and balance, the slopes of these effects were very similar. Conversely, in the case of complexity and symmetry the main effect slopes dropped almost by half in Experiment 2. At the individual level, both experiments show that there is a considerable variation among participants in the extent to which their liking is influenced by contour, symmetry, complexity, and balance. Both experiments confirm that for the four features, a substantial portion of the variance owes to differences among participants in the effects of these features and that models provided a significantly better fit for the data when including the random slopes. In both experiments, aesthetic sensitivities to the four features were barely related. The exception to this was the weak, but significant, positive correlation between aesthetic sensitivity to complexity and to contour in both experiments. In both experiments, participants who liked curved contours the most also liked complex stimuli the most. Finally, in both experiments, we found a weak influence of personality, intelligence, and education measures on aesthetic sensitivity. Art interest and art knowledge were the only scales to show some degree of influence on aesthetic sensitivity, but not in any consistent manner.

Our assessment of the test–retest stability over time of aesthetic sensitivities showed that the measures of contour and balance are stable in time. The differences in aesthetic sensitivity to both of these features measured on both occasions can be attributed to random error. Conversely, the measures of aesthetic sensitivity to symmetry and complexity were systematically biased. As measured with the abridged stimulus set, a small percentage of participants obtained higher scores for aesthetic sensitivity to symmetry in the retest phase, and lower scores for aesthetic sensitivity to complexity in the retest phase.

GENERAL DISCUSSION

Eysenck defined aesthetic sensitivity as a biologically determined ability to appreciate objective beauty. He believed this ability was distinct, in that it was independent from intelligence and personality, and general, in that it applied to many kinds of designs and artworks (Eysenck, 1940, 1941c, 1942). Aesthetic sensitivity could be measured quantitatively. It was simply the difference between someone's liking and a given norm, estimated either by averaging many laypeople's liking or by experts' judgements.

Eysenck's VAST (Götz *et al.*, 1979) was conceived to provide a valid and reliable measure of aesthetic sensitivity. Recent studies, however, revealed the VAST's psychometric weaknesses (Myszkowski & Storme, 2017; Myszkowski & Zenasni, 2016; Myszkowski *et al.*, 2014, 2018). Contrary to Eysenck's conception, aesthetic sensitivity as measured with the VAST is not a distinct ability: It is related to general intelligence, certain personality traits, and certain aspects of creativity (Myszkowski *et al.*, 2014, 2018). In addition to these measurement problems, Eysenck's notion of aesthetic sensitivity stands upon premises that have been rendered invalid with advances in neuroscience and psychology in general and empirical aesthetics in particular (Skov & Nadal, 2018). We have therefore proposed discarding Eysenck's notion of aesthetic sensitivity, and regarding the VAST as a measure of the ability to discriminate between levels of a particular notion of harmony, in line with Gear's (1986) conclusions.

In this paper, we have developed an alternative approach to aesthetic sensitivity. In line with Corradi *et al.* (2019), we have defined aesthetic sensitivity as responsiveness, as the extent to which a given feature influences someone's liking or preference. From the perspective of social judgement theory, our definition of aesthetic sensitivity corresponds to individual differences in judgement policies, that is to say, to the extent to which people's judgements depend on aesthetic cues (Cooksey, 1996; Jacobsen, 2004; Jacobsen & Höfel, 2002; Stewart, 1988). We conducted two experiments. The first aimed to introduce one possible measure of aesthetic sensitivity based on the individual slopes provided by linear mixed-effects models. We characterized aesthetic sensitivity to contour, symmetry, complexity, and balance. The second experiment aimed to replicate the results of the first using an abridged version of the task, and explore the test–retest reliability of this abridged version.

The results of both experiments confirm the general effects that have previously been reported in the literature (Gómez-Puerto *et al.*, 2015, 2018; Höfel & Jacobsen, 2003; Jacobsen & Höfel, 2002; Wilson & Chatterjee, 2005). As a group, participants liked designs with curved contours more than equivalent versions with sharp-angled contours, symmetrical designs more than asymmetrical designs, and their liking increased linearly with complexity and balance.

By applying linear mixed-effects models (Cotter *et al.*, 2017; Gartus & Leder, 2013, 2017; Silvia, 2007), both experiments also uncovered important individual variations in the impact of contour, symmetry, complexity, and balance on liking. In the four cases, individual responsiveness to these features accounted for a large proportion of variance in liking ratings. For some participants, liking was affected by variations in contour, symmetry, complexity, and balance. For other participants, liking was unaffected by such variations; they were indifferent to such features. This adds to the literature showing that group-level models conceal considerable variation among participants in the features that contribute to their liking (Jacobsen, 2004; Jacobsen & Höfel, 2002).

Both experiments also unveiled very weak correlations among aesthetic sensitivities to the four features. The only significant – although weak – correlation in both experiments was between contour and complexity. This indicates that participants who liked curved-contour designs also tended to like complex ones, that participants who liked sharp-angled contour designs tended to like simple ones, and that participants who were indifferent to one feature tended to be indifferent to the other. In sum, aesthetic sensitivity to one feature is either unrelated or only weakly related to aesthetic sensitivity to other features. People are not aesthetically sensitive in general and to all features alike. They seem to be more sensitive to some features than others. This supports the possibility of multiple relatively independent aesthetic sensitivities. Further work is required to determine the dimensions underlying aesthetic sensitivity to different features (Stich *et al.*, 2007).

In both of our experiments we found little evidence that aesthetic sensitivity to contour, symmetry, complexity, and balance is related to intelligence, openness to experience, desire for aesthetics, art interest, or art knowledge. These variables were either unrelated to aesthetic sensitivity, or only weakly and inconsistently related. Further research is also needed on this front, to better understand the relation between intelligence, personality, and experience and aesthetic sensitivity.

The results of the test–retest assessment suggest that our abridged set of stimuli has an adequate test–retest reliability regarding balance and contour, and moderate regarding symmetry and complexity. Our motivation to put together a stimulus set that is efficient for research and can be applied quickly might led us to reduce the number of stimuli excessively. Experiment 1 included between 60 and 66 items in each subset, whereas Experiment 2 included only between 20 and 24. It is possible that using between 40 and 44 items for each dimension will increase the reliability of the measures of aesthetic sensitivity to symmetry and complexity.

Our results can be seen as an extension of the application of the concepts and methods of judgement analysis, or policy capturing, to the domain of aesthetics, pioneered by Thomas Jacobsen and colleagues (Höfel & Jacobsen, 2003; Jacobsen, 2004; Jacobsen & Höfel, 2002, 2003; Jacobsen, Schubotz, Höfel, & von Cramon, 2006). One of our major steps forward, in this sense, was our use of linear mixed-effects models, which combine individual- and group-level models, a substantial advance in comparison to the common use of multiple regressions. Originally, judgement analysis was designed to quantify the relation between a person's judgement and the cues used to make that judgement (Stewart, 1988). It was intended to study experts in their natural settings making judgements about problems that are familiar to them, such as meteorologists in a laboratory forecasting the weather, or physicians in a hospital diagnosing patients (Cooksey, 1996; Stewart, 1988). When applied to situations like ours, where participants were asked to judge unfamiliar stimuli in an unfamiliar setting, it is better to conceive these as studies on policy construction, rather than on policy capturing (Brehmer & Brehmer, 1988). Because participants had not previously seen the stimuli they are asked to respond to, they did not have a developed policy; they had to develop such a policy in the course of the experimental session. The replication of the results of Experiment 1 in Experiment 2, and the reasonable temporal stability observed in the test–retest analysis, suggest that although people constructed their judgement policies in the course of the experimental sessions, they did so in a consistent manner. Our concept of aesthetic sensitivity corresponds to the kind of policy constructed by our participants. Some consistently developed a policy whereby the cues were irrelevant to judging the presented items (aesthetically insensitive). Most, however, consistently developed a policy whereby the cues were used to judge them as more or less liked or disliked.

To conclude, we have developed a new conception of aesthetic sensitivity defined as the degree to which someone's liking is influenced by a given visual feature (Corradi *et al.*, 2019). Two experiments confirm that although at a group level people like stimuli that are curved more than sharp, symmetrical more than asymmetrical, complex more than simple, and balanced more than unbalanced, there is remarkable variation among individual liking judgements. The methods and results of these experiments should encourage future researchers to examine individual differences in the extent to which object features influence aesthetic valuation. Group averages cannot continue to be treated as indicative of uniformity. We have not found compelling evidence that aesthetic sensitivity to one feature is related to aesthetic sensitivity to another, nor that aesthetic sensitivity is related to intelligence, personality, art interest, or art knowledge. But further research is definitively required to confirm this.

Variations in aesthetic sensitivity should not be treated as noise. Not everyone is cast in the same mould when it comes to aesthetic valuation. People weigh different visual features differently. Understanding why people differ in the extent to which their aesthetic valuation responds to complexity, symmetry, balance, contour, as well as other sensory features and object features (Stich *et al.*, 2007), has the potential to illuminate the process of aesthetic valuation itself. Variations in aesthetic sensitivity deserve to be studied and explained: Why are some people more aesthetically sensitive to complexity than others? Can training alter aesthetic sensitivity? Can contextual cues modulate aesthetic sensitivity? How do the different aesthetic sensitivities integrate in different people to produce an overall aesthetic value? Does aesthetic sensitivity cut across sensory domains? If people are sensitive to visual complexity, are they also sensitive to musical complexity?

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Reply to Myszkowski et al. (2020):

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Commentary

Reply to Myszkowski et al. (2020): Some matters of fact concerning aesthetic sensitivity

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We respond to some of Myszkowski and colleagues' (2020, *Br. J. Psychology*) critical comments on our recent work on aesthetic sensitivity (Corradi, Chuquichambi, Barrada, Clemente, & Nadal, 2020, *Br. J. Psychology*). We show that these comments stem mostly from factual inaccuracies.

We thank Myszkowski *et al.* (2020) for their critical comments on our recent work on aesthetic sensitivity (Corradi, Chuquichambi, Barrada, Clemente, & Nadal, 2020). We are also very grateful to the editors of the British Journal of Psychology for enabling this discussion. Too many ideas in empirical aesthetics have never been thoroughly examined and debated. We cannot address each of Myszkowski *et al.'s* (2020) points in a short response. We will be selective, showing how their criticisms stem from factual inaccuracies.

First, Myszkowski *et al.* (2020) claim that 'Since Thorndike (1916), it has been clearly admitted that the aesthetic value of a stimulus is actually only determined by expert consensus'. This statement is wrong historically, psychologically, and neuroscientifically. Historically, because expert consensus changes: Impressionism was initially rejected by experts, only to be revered by the next generation of experts. Which experts determined the true aesthetic value of impressionism? Psychologically, because from Fechner to the present, hundreds of empirical studies have identified many other determinants of aesthetic value. Neuroscientifically, because aesthetic value is determined by the brain's reward system assessing sensory information according to current state, goals, and expectations (for a review, see Skov, 2019).

Second, Myszkowski *et al.* (2020) claim that aesthetic sensitivity, 'as the ability to identify (consensually/expertly defined) aesthetic value for over a century, is clearly conceptually defined'. This is misleading. It is, in fact, unclear what this ability actually involves. It is even unclear who the purported experts are. In Child's (1965) work, the experts were only 14 judges: 'mostly students in the School of Art at Yale, some were graduate students in history of art, and some were older people in the New Haven area with similar qualifications' (Child, 1965, p. 477). Only in 37% of the cases did all *or almost*

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all experts agree. In Eysenck's VAST, the experts were only 'eight well-known painters' (Götz, Borisy, Lynn, & Eysenck, 1979, p. 796), of whom no further information is given. Is aesthetic sensitivity, thus, the ability to make judgments in accordance with 14 art and art history students at Yale during the 1960s, who disagree 63% of the cases, or in accordance with 8 unknown well-known artists in the 1970s? The fact is that the ability conception of aesthetic sensitivity rests on questionable notions of *expertise* and *consensus*.

Finally, Myszkowski *et al.* (2020) claim we are attacking the ability approach of aesthetic sensitivity, but that it is Child's conception, not Eysenck's: 'Child's (1964) definition of aesthetic sensitivity, which is currently the most used for the construct, clearly describes aesthetic sensitivity as the ability to 'judge in relation to external standards''. Myszkowski *et al.* (2020) are wrong. Child (1964) did not conceive aesthetic sensitivity as a specific ability, but as the expression of general cognitive style, personality, and experience, as 'an outcome of a general cognitive approach to the world, an approach involving search for complex and novel experience which is then understood and evaluated through relatively autonomous interaction of the individual with objects providing such experience' (Child, 1965, p. 510).

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Conflicts of interest

All authors declare no conflict of interest.

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VII

A Set of 200 Musical Stimuli Varying in Balance, Contour, Symmetry, and Complexity:

Behavioral and Computational Assessments

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A Set of 200 Musical Stimuli Varying in Balance, Contour, Symmetry, and Complexity: Behavioral and Computational Assessments

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Abstract

We present a novel set of 200 Western tonal musical stimuli (MUST) to be used in research on perception and appreciation of music. It consists of four subsets of 50 stimuli varying in balance, contour, symmetry, or complexity. All are 4 s long and designed to be musically appealing and experimentally controlled. We assessed them behaviorally and computationally. The behavioral assessment (Study 1) aimed to determine whether musically untrained participants could identify variations in each attribute. Forty-three participants rated the stimuli in each subset on the corresponding attribute. We found that inter-rater reliability was high and that the ratings mirrored the design features well. Participants' ratings also served to create an abridged set of 24 stimuli per subset. The computational assessment (Study 2) required the development of a specific battery of computational measures describing the structural properties of each stimulus. We distilled nonredundant composite measures for each attribute and examined whether they predicted participants' ratings. Our results show that the composite measures indeed predicted participants' ratings. Moreover, the composite complexity measure predicted complexity ratings as well as existing models of musical complexity. We conclude that the four subsets are suitable for use in studies that require presenting participants with short musical motifs varying in balance, contour, symmetry, or complexity, and that the stimuli and the computational measures are valuable resources for research in music psychology, empirical aesthetics, music information retrieval, and musicology. The MUST set and MATLAB toolbox codifying the computational measures are freely available at osf.io/bfxz7.

Keywords music · aesthetics · MIR · balance · contour · symmetry · complexity

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Introduction

Valuing objects is crucial for making decisions, comparing and choosing among alternatives, and prioritizing actions (Berridge & Kringelbach, 2013; Kringelbach, & Berridge, 2009; Levy & Glimcher, 2012). Music is ideally suited for studying evaluative judgments, for three reasons: First, it is a good example of a cultural product whose appreciation relies on basic and general valuation systems (Mallik, Chandra, & Levitin, 2017; Salimpoor & Zatorre, 2013; Shepard, 1982; Trehub & Hannon, 2006). Second, music combines many features of sound to produce virtually unlimited works that vary across composers, styles, times, and cultures (Cross, 2006; Rohrmeier, Zuidema, Wiggins, & Scharff, 2015; Trainor & Unrau, 2011). Finally, people place a high personal value on music (Nieminen, Istók, Brattico, Tervaniemi, & Huotilainen, 2011): they use it to regulate their emotions (Thoma, Ryf, Mohiyeddini, Ehlert, & Nater, 2012) and to enhance the cohesion and coordination in groups (Dissanayake, 2008; Savage, Brown, Sakai, & Currie, 2015), and they are willing to invest time, effort, and money in recorded and live performances (Huron, 2003; Müllensiefen, Gingras, Musil, & Stewart, 2014).

The valuation of music involves the interaction of modality-specific and modality-general attributes (Marin, Lampatz, Wandl, & Leder, 2016; Marin & Leder, 2013; Purwins et al., 2008). Its aesthetic appreciation depends on many factors, including familiarity, perceived complexity, and predictability (Brattico & Pearce, 2013; Edmonston, 1969; Heyduk, 1975; Koelsch, Vuust, & Friston, 2018; Payne, 1980; Pereira et al., 2011; Van den Bosch, Salimpoor, & Zatorre, 2013), which also mediate the valuation of visual stimuli, from architecture to design and art (De Lange, Heilbron, & Kok, 2018; Forsythe, Mulhern, & Sawey, 2008; Forsythe, Nadal, Sheehy, Cela-Conde, & Sawey, 2011; Madison & Schiölde, 2017; Tinio & Leder, 2009). Aside from the roles of these factors, however, little is known about the extent to which the valuation of musical and visual objects relies on common attributes. With few exceptions (e.g., complexity in Marin & Leder, 2013), a direct examination of their influence on the valuation of music and visual stimuli has been prevented by the absence of materials comparable across modalities.

In this paper, our goal was to facilitate research on modality-general attributes and domain-general processes in the valuation of music by (1) creating a set of musical stimuli (MUST) suitable for studying modality-general attributes in the valuation of music; (2) assessing the stimulus set behaviorally and computationally; (3) analyzing how both kinds of assessments relate to each other, to stimulus design features, and to existing measures of complexity; and (4) making the MUST set and computational measures available to other researchers through the Open Science Framework (OSF) at osf.io/bfxz7. We designed the set and computational measures to be useful in many fields, including empirical aesthetics, musicology, music psychology, and music information retrieval.

We focused on four attributes: balance, contour, symmetry, and complexity. Their influence on the valuation of visual stimuli is well tested (Gartus & Leder, 2017; Gómez-Puerto, Munar, & Nadal, 2015; Jakesch & Leder, 2015; Locher, Gray, & Nodine, 1996; Palumbo & Bertamini, 2016; Tinio & Leder, 2009; Van Geert & Wagemans, 2019; Vartanian et al., 2019; Wilson & Chatterjee, 2005). For instance, research in empirical aesthetics indicates that people generally prefer objects and designs that are symmetric (Jacobsen & Höfel, 2002; Gartus & Leder, 2013), complex (Nadal, Munar, Marty, & Cela-Conde, 2010; Machado et al., 2015), balanced (Wilson & Chatterjee, 2005), and curved (Bertamini, Palumbo, Gheorghes, & Galatsidas, 2016; Corradi, Chuquichambi, Barrada, Clemente, & Nadal, 2019). Most of these preferences seem to transcend boundaries of culture (Che, Sun, Gallardo, & Nadal, 2018) and even species (Munar, Gómez-Puerto, Call, & Nadal, 2015).

The effects of these attributes on evaluative judgments are not confined to the visual domain. Evaluative judgments of music are also influenced by contour (e.g., Gerardi & Gerken, 1995; Schmuckler, 2015; Thorpe, 1986; Trehub, Bull, & Thorpe, 1984), symmetry (e.g., Balch, 1981; Bianchi, Burro, Pezzola, & Savardi, 2017; Krumhansl, Sandell, & Sergeant, 1987; Mongoven & Carbon, 2017), complexity (e.g., Marin & Leder, 2013; Pressing, 1999; Steck & Machotka, 1975; Streich, 2007), balance, and proportion (Juslin, 2013; Winner, Rosenblatt, Windmueller, Davidson, & Gardner, 1986), as accounted for by a large number of musicological and music-theoretical studies (e.g., Cook, 1987; Grey, 1988) and treatises on form (e.g., Caplin, Hepokoski, & Webster, 2010; Leichtentritt, 1911) and composition (e.g., Schoenberg, A., 1967). Could the fact that balance, contour, symmetry, and complexity influence evaluative judgments in the visual and musical domains owe to cross-modal processes? Testing this intriguing possibility requires, however, materials that are directly comparable, analogous in specific dimensions in the auditory and visual modalities.

We intended our stimuli to be both musically appealing and experimentally controlled. Excerpts from the existing repertoire (e.g., Marin & Leder, 2013; Egermann, Pearce, Wiggins, & McAdams; 2013; Gingras et al., 2016) have the advantage of being naturalistic, but also the drawback that some might be more familiar than others, have different duration, and include other sources of uncontrolled variability. Conversely, controlled sequences of synthesized sounds can minimize extraneous variables (e.g., Shmulevich & Povel, 2000; Steck & Machotka, 1975), but they also reduce musical appeal and ecological validity. We therefore chose to compose motifs that combine the musical appeal of genuine musical excerpts with the experimental control of synthesized sequences.

Once the stimuli were composed, we subjected them to two assessments. First, we conducted a behavioral experiment (Study 1) to determine whether the design parameters we manipulated to produce variations in balance, contour, symmetry, and complexity translated into perceived variations in each of these attributes by musically untrained participants. Based on the results of this experiment, we created an abridged set of stimuli to be used more efficiently in experimental settings. Second, we developed several computational measures for each parameter manipulated to compose the stimuli (Study 2). These computational measures served (i) to describe each motif in terms of structural properties, (ii) to derive nonredundant composite measures for each attribute (balance, contour, symmetry, and complexity), (iii) to ascertain which of the composite measures, or combination thereof, explain participants' assessments of the stimuli attributes in the behavioral experiment, and (iv) to compare the explanatory adequacy of our composite measures of complexity with other objective methods for computing musical complexity.

Design of the musical stimuli

The MUST set consists of 200 original musical motifs composed by the first author—an accomplished professional musician with broad compositional and performing experience—using Finale 2012 (MakeMusic Coda Music Technologies), and comprising four subsets of 50 stimuli that vary in terms of a specific attribute: Balance, Contour, Symmetry, and Complexity. Four additional motifs were composed for each subset to be used as examples while giving experimental instructions.

The motifs in the MUST Balance subset capture and translate into music the variation in balance among the visual stimuli in Wilson and Chatterjee's (2005) set. This set consists of diverse arrangements of seven hexagons or circles of distinct sizes. These stimuli were created to vary in balance, measured as the average of eight symmetry components over the axes of the stimuli (Fig. 1, first column). The motifs in the Contour subset reflect the kind of variation between the curved and sharp contours of Bertamini et al.'s (2016) visual stimuli. These stimuli were designed as closed black figures based on circles, ovals, or lobed ovals, and matched in the number of vertices. Half of them had curved contours, and the other half had sharp-angled contours (Fig. 1, second column). The musical motifs in the Symmetry and Complexity MUST subsets were composed to capture the variation in symmetry and complexity in Jacobsen and Höfel's (2002) set of visual designs. This set consists of a series of images of solid black circles with a centered white square containing triangles that are combined to form designs of varying complexity and symmetry. Half of the configurations are symmetric, and the other half, asymmetric, and the stimuli in both halves match for different degrees of complexity, corresponding to the number of constituent elements (Fig. 1, third and fourth columns). Unlike Jacobsen and Höfel (2002), who developed visual designs varying in both symmetry and complexity, we present a subset varying in complexity and a separate one varying in symmetry.

The composer used her musical and artistic expertise to manipulate specific musical parameters to generate variation within each target attribute: balance, contour, symmetry, and complexity (Table 1). The compositional process also aimed to make the set coherent, and the stimuli comparable across sensory modalities and equivalent in musical attributes.

Mirroring the sets of visual images described above, the motifs in the Complexity subset vary along a continuum (from *simpler* to *more complex*). In contrast, those in the other three sets belong to one of two poles: *balanced* vs. *unbalanced* (Balance), *smooth* vs. *jagged* (Contour), and *symmetric* vs. *asymmetric* (Symmetry) (see Fig. 2 for examples of the scores, and Table 1 for the parameters used to design the stimuli). For the Balance, Contour, and Symmetry subsets, the stimuli were designed to achieve high between-pole and low within-pole variation in the target parameters, while minimizing variation in the other parameters. Because timbre and intensity are constant across all stimuli, variations in the four attributes were created using pitch, rhythm, and harmonic implication.

Balance subset Stimuli vary in their equilibrium, as applied both to the distribution of notes throughout the motif and to the distance of the tensional peak from the central time point.

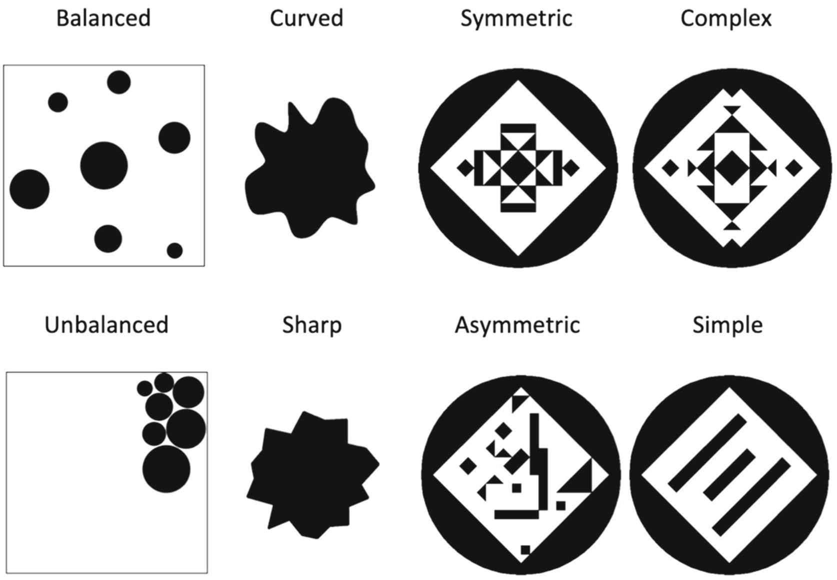

Fig. 1 Examples of visual stimuli designed by Wilson & Chatterjee (2005) for balance; Bertamini, Palumbo, Gheorghes, & Galatsidas (2016) for contour; and Jacobsen & Höfel (2002) for symmetry and complexity

Table 1 Summary of parameters used to design the musical stimuli in each subset

Attribute	Parameter	Feature	
Balance		***Balanced***	***Unbalanced***
	Distribution of elements/events	Regular	Irregular
	Climax position	Centered	Skewed
	Tension	Progressive	Unprepared
Contour		***Smooth***	***Jagged***
	Intervals	Only small (≤ fourths)	Large (> fourths) & small
	Durations	Progressive, small changes	Sudden, large changes
Symmetry		**Symmetric**	**Asymmetric**
	Vertical mirror structure	Yes	No
Complexity		***Simpler***	***More complex***
	Number of elements/events	Few	Many
	Variety of elements/events	Low	High
	Predictability	High	Low

Melodic and harmonic tension contribute to the climax and consequently to balance, but for such brief and constrained stimuli, it stands to reason that they play a weaker role than the distribution of notes in time. A motif is *balanced* if its notes are uniformly distributed with relation to a central climax (or center of mass, in analogy to physical gravity). A motif is *unbalanced* if most notes accumulate at either the beginning or ending.

Contour subset Stimuli differ in terms of interval size and rhythmic change, leading to differences in the profile of their melodic line. Although contour may also refer to the direction
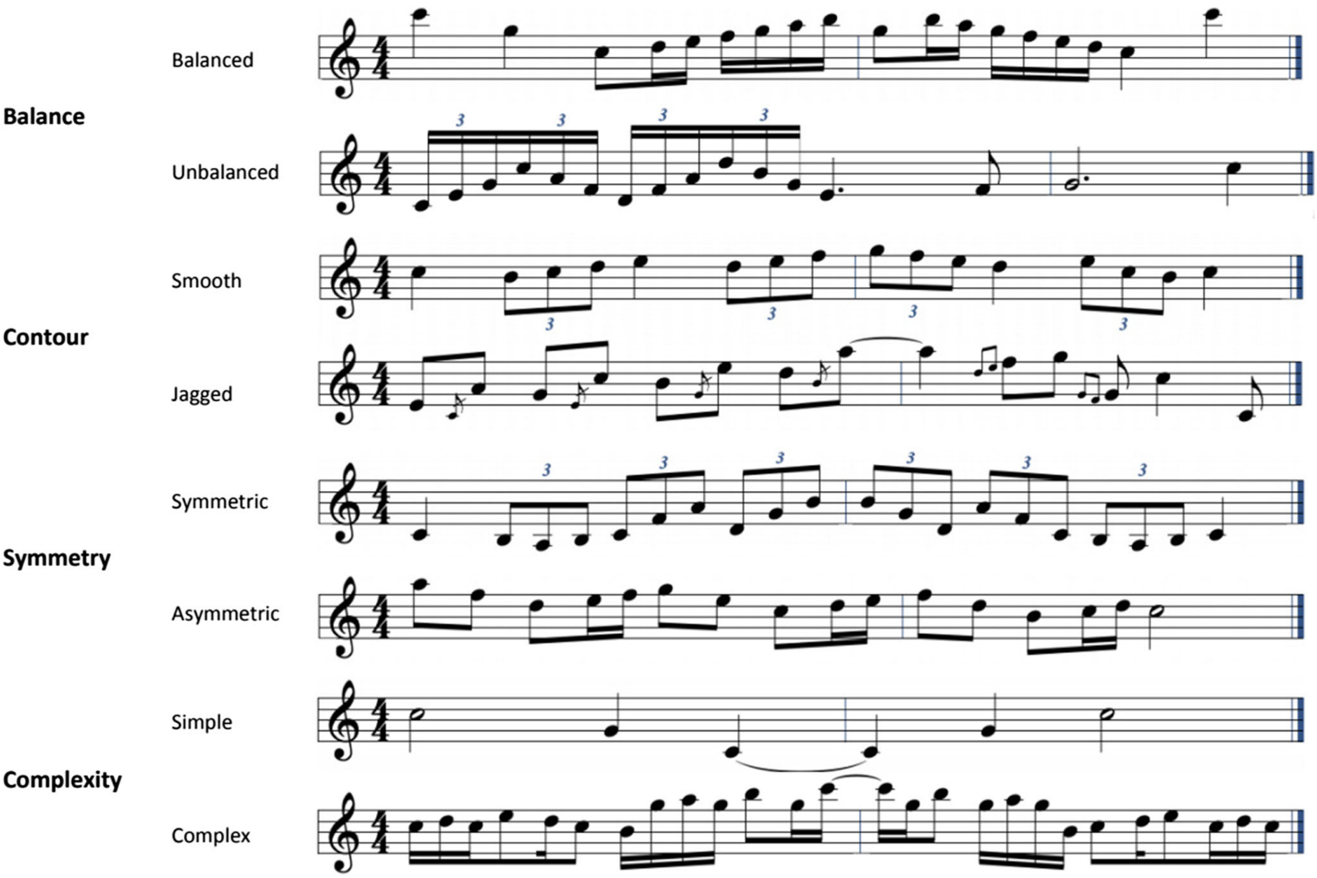
Fig. 2 Musical stimuli sample scores in each subset, all to be played at q = 120 (i.e., quarter note at 120 bpm)

of melodic movement (i.e., rising, falling, or constant pitch intervals regardless of their size), we define it as melodic shape or configuration, thus determined by interval size and duration (or onset) ratios. Therefore, for the *smooth* motifs, we used only small intervals (≤ fourths, predominantly seconds) and rhythms in which successive note durations change very little, while *jagged* motifs included large intervals (> fourths) and sudden rhythmic shifts.

Symmetry subset Stimuli differ to the extent they are symmetrical around a central vertical axis. In *symmetric* motifs, the second half is a literal retrograde repetition of the first half. They thus have a mirror reflection structure—e.g., A(B)A, ABC(C)BA. The only exception to strict symmetry is that the duration of the first and last notes may not be equal because of notational constraints. In *asymmetric* motifs, there is no such retrograde repetition.

Complexity subset Stimuli vary in the number, variety, and predictability of their elements or events. *More complex* motifs have many notes varying widely in duration, pitch interval size, and register. Conversely, *simpler* motifs are characterized by a small number of highly predictable notes with repeated uncomplicated patterns.

We strove to minimize variation in all attributes other than the intended one, even though we expected some intercorrelations between the parameters defining different attributes. For instance, all other parameters being equal, *symmetric* patterns will be judged as simpler than *asymmetric* designs, both in the visual and the auditory modalities, as they imply redundancy by definition. This is why all stimuli in the Complexity subset are symmetric, all included in Contour and Balance are asymmetric, and all stimuli in the Symmetry subset have medium to low complexity (as complexity hampers the perception of symmetry; Mongoven & Carbon, 2017). We obtained estimates of the file sizes of the musical motifs using lossless compression format FLAC (Free Lossless Audio Codec) to uncompressed WAV (Waveform Audio File Format) files, for it appears to be a good approximation of complexity ratings of musical stimuli (Marin & Leder, 2013). This enabled us to ensure that the *asymmetric* and *symmetric* poles of the Symmetry subset did not differ significantly in terms of complexity ($t_{(48)} = 1.595$, $p = .117$) as assessed by FLAC compression. Just like visual curves imply more information than polygons, the pitch entropy is higher by definition in the *jagged* than in the *smooth* stimuli. However, the *t*-tests revealed no significant differences between the poles of the Contour subset ($t_{(48)} = 2.007$, $p = .050$). In contrast, the FLAC compression sizes of the *unbalanced* motifs were, overall, significantly larger than those of the *balanced* ones ($t_{(48)} = 6.555$, $p < .001$), probably because self-similarity may be higher in balanced designs. Furthermore, symmetry in the visual and music domains can be regarded as an extreme form of balance. Therefore, all motifs except the *unbalanced* were composed with a high degree of balance. Finally, all except those in the Contour subset possessed medium contours (not too jagged, not too smooth).

Short monophonic melodies are the musical analogues to the abstract visual patterns in the visual sets. Although musical pieces are often polyphonic, we retained the underlying harmony in our motifs, together with the factors related to the stimulus that may define the attributes in both short monophonic and long polyphonic music. To avoid harmony being unduly affected by the manipulations, we carefully used simple harmonic sequences and rhythmic figures, thereby maintaining the musical structure and style similar for both poles in the Balance, Contour, and Symmetry subsets. Finally, tessiture and tempi were compensated within subsets and never extreme. The fastest tempo is 180 bpm, and the pitch range spans from C_2 to C_6 (provided $A_4 = 440$ Hz), approximately the human vocal range.

All stimuli were composed using the same musical idiom, including language and style (Western tonal-functional), key (C Major), texture (monophonic), timbre (piano-like; Garritan Sound Library for Finale, MakeMusic), duration (4 s), overall and instantaneous loudness (no changes in musical dynamics or spatial cues), and other acoustical properties (i.e., expressive performance and recording inconsistencies and variability are nonexistent). A length of 4 s seems optimal for experimental settings where visual correspondence is of relevance, because it does not imply an excessive working memory load and approximates presentation times of images in studies of visual aesthetics, allowing comparisons between auditory and visual research findings. Moreover, nonmusicians' short-term memory for music is thought to span about 3–5 s (Schaal, Banissy, & Lange, 2015; Snyder & Snyder, 2000), and the perception of musical symmetry is optimal within this duration (Mongoven & Carbon, 2017; Petrović, Ačić, & Milanković, 2017).

Study 1: Behavioral assessment of musical stimuli

Method

Participants

Forty-three self-reported nonmusicians (none of whom had ever received higher education in music or was a professional musician; see full questionnaire in Appendix A, Supplementary Materials) aged 18–55 years ($M = 29.31$, $SD = 10.56$, 24 female, 18 male, one not reported) took part in the study. All gave informed consent before participating and reported normal or corrected-to-normal vision and hearing, and no cognitive impairments. Participants were unaware of the purpose of the study, and all study procedures followed local ethical guidelines and the Declaration of Helsinki.

Materials

The stimuli were the 200 motifs described above, and the four example stimuli for each subset, presented in WAV format using Open Sesame (Mathôt, Schreij, & Theeuwes, 2012).

Procedure

The study was conducted at the Laboratory of Psychology of the University of the Balearic Islands. Each of the 43 participants rated each of the 50 musical motifs in each subset presented as a different experimental block consisting of instructions (available in Appendix A), four examples (two for each pole) to illustrate the instructions, five practice trials, and the experimental task itself. The five stimuli for the practice trials were selected from the 50 in each subset, counterbalanced across participants. Thus, although participants rated 45 stimuli in each subset, all 50 stimuli received ratings. The order of the blocks was also counterbalanced. The order of the 45 stimuli used in the experimental task was randomized individually. All stimuli were presented in sound-attenuated cabins through headphones.

At the beginning of each block, a text introduced and defined the attribute according to its design parameters, and four illustrative examples were played. During the first examples, the participants adjusted headsets and volume to personal comfort levels, which remained unmodified throughout the experiment. They then rated the five practice stimuli under the experimenter's supervision and assistance. After the experimenter had made sure that participants understood the task and all doubts had been resolved, the participants rated the 45 remaining stimuli alone using Likert scales ranging from 1 to 5 and anchored by *very balanced* (1) and *very unbalanced* (5) for Balance, *very smooth* (1) and *very jagged* (5) for Contour, *very symmetric* (1) and *very asymmetric* (5) for Symmetry, and *very simple* (1) and *very complex* (5) for Complexity. The rating scale appeared after each musical motif had ended, and served as a cue for response. The rating was self-paced, and the participants could play each stimulus as many times as they wished before rating it. The procedure was the same for all blocks. After finishing each block, the participants could rest for a moment before going on to the next. A brief questionnaire followed the last block, recording information on demographics, musical education, and general feedback (included in Appendix A). The whole experimental session lasted about 40 minutes, after which the participants were debriefed and thanked.

Data analysis

This behavioral assessment had two objectives. The first was to determine whether untrained participants perceived variations in the defining attribute for each subset, that is to say, whether stimuli designed to be more complex, for instance, would indeed be perceived and rated by nonmusicians as more complex. To this end, we first assessed inter-rater reliability for each subset using intraclass correlation coefficients ($ICC_{3,k}$; Shrout & Fleiss, 1979). We then conducted Wilcoxon signed-rank tests (given that the Shapiro–Wilk test of normality revealed that several of the distributions were not normal) to determine whether mean ratings for stimuli in each pole in the dichotomous subsets (Balance, Contour, and Symmetry) differed significantly. For the continuous subset (Complexity), we calculated the Spearman correlation between the FLAC file size of each musical motif and its mean rating.

The second aim was to select part of the musical motifs in each subset to assemble an abridged set that could be applied in future studies in a shorter session. We wished to include motifs that participants agreed belonged to the different poles in each subset. Following Nadal et al.'s (2010) method, we calculated the mean and standard deviation of each stimulus' ratings. For each subset, we selected the 12 stimuli with the highest mean rating and the 12 stimuli with the lowest mean rating (those perceived as most *balanced*, *smooth*, *symmetric*, and *simple*, and those perceived as the most *unbalanced*, *jagged*, *asymmetric*, and *complex*), provided the standard deviation of participants' ratings was below the 75th percentile, and that the mean rating placed the motif in the pole it was designed to be in. We thus assembled four subsets containing 24 stimuli each, 12 in each pole, maximizing the difference between and minimizing the difference within levels. This ensured that stimuli represented extreme poles of each dimension and that participants did not disagree on their allocation. Finally, to verify whether the motifs in each pole of each subset of the abridged set actually corresponded to different levels, we compared their mean ratings using Wilcoxon nonparametric tests.

Results

Inter-rater reliability

The average fixed raters' ICC was high for all subsets: for Balance, $ICC_{3,k} = .94$, 95% CI [.92, .96]; for Contour, $ICC_{3,k} = .97$ [.96, .98]; for Symmetry, $ICC_{3,k} = .84$ [.77, .90]; for Complexity, $ICC_{3,k} = .99$ [.98, .99]. These values show that participants understood the task and judged the stimuli in very similar ways.

Ratings of attributes

According to the Shapiro–Wilk tests, the mean ratings of each motif were not normally distributed for the Balance ($W = 0.842$, $p < .001$, skew $= -0.092$, kurtosis $= -1.788$), Contour ($W = 0.843$, $p < .001$, skew $= 0.052$, kurtosis $= -1.790$), and Complexity ($W = 0.85147$, $p < .001$, skew $= -0.713$, kurtosis $= -1.040$) subsets, whereas the distribution of Symmetry ratings did not differ significantly from normality ($W = 0.982$, $p = 0.628$).

Participants' ratings corresponded well to the design features of musical motifs in each subset (Fig. 3). Wilcoxon tests showed significant differences between the mean ratings of *balanced* ($M = 2.2$, $SD = 0.3$) and *unbalanced* ($M = 3.82$, $SD = 0.18$) motifs in the Balance subset ($W = 0$, $p < .001$), between *jagged* ($M = 3.99$, $SD = 0.32$) and *smooth* ($M = 2.06$, $SD = 0.25$) motifs in the Contour subset ($W = 625$, $p < .001$), and between *asymmetric* ($M = 3.09$, $SD = 0.54$) and *symmetric* ($M = 2.47$, $SD = 0.41$) motifs in the Symmetry subset ($W = 513$, $p < .001$). Spearman correlation analysis indicated a strong relation between the FLAC file size and mean rating for the motifs in the Complexity subset ($r_s = .78$, $p < .001$). In sum, reflecting the design features of the stimuli, participants gave higher unbalance scores to the *unbalanced* stimuli than to the *balanced* stimuli, higher jaggedness scores to *jagged* than to *smooth* stimuli, higher asymmetry scores to *asymmetric* than to *symmetric* stimuli, and higher complexity scores to *complex* than to *simple* stimuli.

Creation of the abridged set

Following the procedure described above, we selected the 12 stimuli that received the most extreme ratings of balance and unbalance, smoothness and jaggedness, symmetry and asymmetry, and simplicity and complexity, provided there was no strong disagreement among the raters (Balance $SD_{75\text{th}} = 1.40$; Contour $SD_{75\text{th}} = 1.26$; Symmetry $SD_{75\text{th}} = 1.57$; Complexity $SD_{75\text{th}} = 1.01$). We also selected two additional stimuli from each pole of each subset (the next two most extreme items) to be used as practice trials when employing the abridged set. The whole abridged set therefore includes 96 musical motifs representing the extreme poles of balance, contour, symmetry, and complexity, plus 16 practice stimuli. The list is available in Appendix C in the Supplementary Materials.

Figure 4 graphically represents the relation between the mean and the standard deviation of the ratings for each stimulus. The general trend, at least in the Symmetry and Complexity subsets, is for participants to agree more in their ratings of stimuli close to the extreme of the poles, and less in their rating of stimuli far from the poles. Wilcoxon tests indicated that for each of the abridged subsets, the selected stimuli in each pole (filled dots in Fig. 4) received significantly different ratings (for each of the four abridged subsets separately, $W = 0$, $p < .001$). Thus, in the abridged subsets, the rated unbalance for *unbalanced* stimuli ($M = 3.92$, $SD = 0.1$) was higher than for *balanced* stimuli ($M = 2.01$, $SD = 0.17$), the rated jaggedness for *jagged* stimuli ($M = 4.16$, $SD = 0.22$)

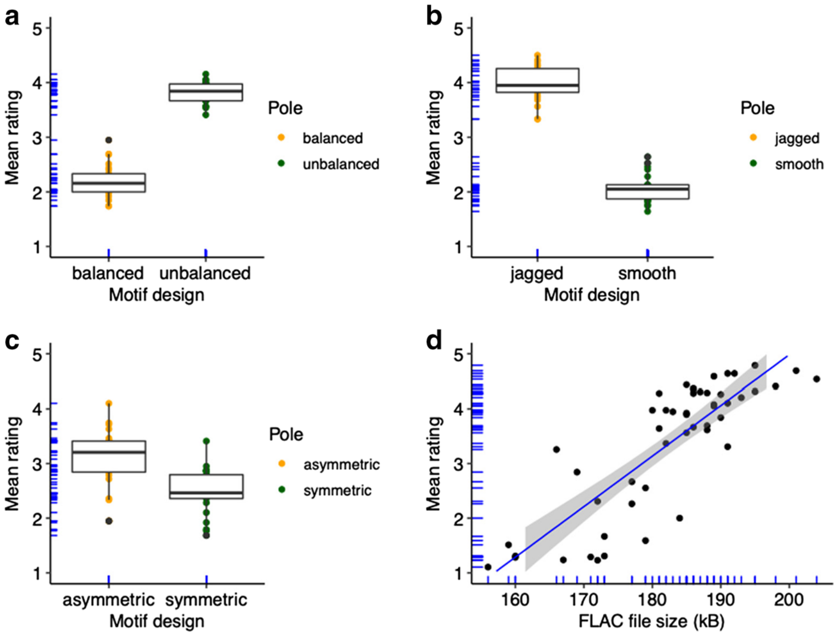

Fig. 3 Correspondence between the behavioral assessment and the design of the motifs. Boxplots are used for the discrete subsets of Balance (**a**), Contour (**b**), Symmetry (**c**), and a scatterplot illustrates the continuous subset Complexity (**d**). The boxes represent the median, first and third quartiles; whiskers span Q1 − 1.5 × IQR (interquartile range) to Q3 + 1.5 × IQR. For the Complexity subset (d), the regression line is depicted with its 95% CI (gray ribbon). kB refers to kilobytes. The figure includes rug plots of mean ratings (left), and FLAC file size for the Complexity subset (bottom)

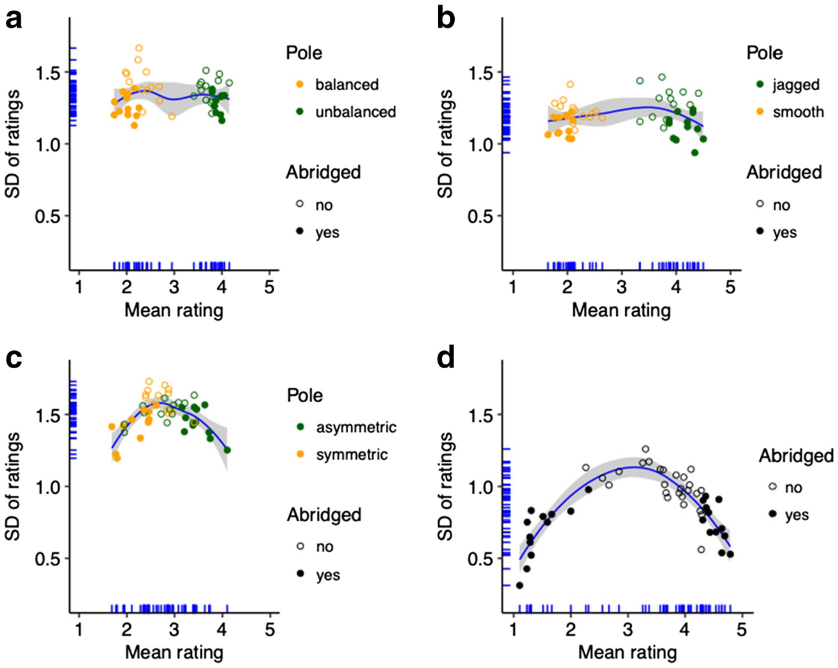

Fig. 4 Distribution of means and standard deviations of ratings for each musical motif in each subset: Balance (**a**), Contour (**b**), Symmetry (**c**), and Complexity (**d**). Filled dots correspond to motifs selected for the abridged set. The figure includes rug plots of the mean (bottom) and the standard deviation (*SD*) of the ratings (left). Curved lines depict local polynomial regression fitting (*SD* ratings ~ *M* ratings), for which the gray ribbon represents the 95% CI

was higher than for *smooth* stimuli ($M = 1.93$, $SD = 0.15$), the rated asymmetry for *asymmetric* stimuli ($M = 3.49$, $SD = 0.27$) was higher than for *symmetric* stimuli ($M = 2.2$, $SD = 0.33$), and the rated complexity was higher for *complex* stimuli ($M = 4.51$, $SD = 0.16$) than for *simple* stimuli ($M = 1.49$, $SD = 0.36$).

Discussion

The overarching goal of our research was to facilitate the investigation of modality-general attributes and domain-general processes in the valuation of music (see also Margulis, 2016). To this end, we created four subsets of 50 brief musical motifs varying along a single dimension (balance, contour, symmetry, or complexity) for use in empirical aesthetics, musicology, music psychology, and other fields. We conducted a behavioral assessment of the stimuli with two aims: First, we wished to determine whether musically untrained participants noticed the variations in each subset, that is, whether they could distinguish between the *balanced* and *unbalanced*, *smooth* and *jagged*, *symmetric* and *asymmetric*, and *simpler* and *more complex* motifs. Second, we wished to assemble an abridged version of our four subsets that could be applied in future studies in a shorter session.

The results of the behavioral assessment show that participants were clearly able to distinguish the stimuli with respect to their defining attribute. This means, first, that variations in each of the attributes were readily perceptible to participants, and second, that participants' ratings concurred with the design of the stimuli. The results also revealed a very high inter-rater reliability, suggesting that participants understood the task in a similar way and judged the musical motifs using common criteria. This holds for all subsets, although the differentiation between *symmetric* and *asymmetric* motifs of the Symmetric subset seems to be less apparent than the distinction between the poles of other dichotomous subsets. A plausible explanation is that musical symmetry may require higher memory load and levels of attention than other attributes: one would have to memorize and compare events of the motif several seconds apart and in reversed order with high accuracy to discern whether it is symmetric (Krumhansl et al., 1987; Mongoven & Carbon, 2017). Nevertheless, even though slightly lower, the inter-rater reliability was still high, and while the standard deviations were slightly higher for the Symmetry subset, these values were not excessive, and the mean ratings for each pole were significantly different. Participants' ratings, in sum, reliably mirrored the design parameters of the musical motifs. We conclude, therefore, that the four subsets are suitable for use in future studies that require presenting participants with short musical motifs varying in balance, contour, symmetry, or complexity.

The presentation of 50 stimuli in each subset might be too long in some studies. We therefore used the ratings provided by our participants to derive an abridged version of each subset, selecting the 24 stimuli that represented the most extreme poles of each attribute, and for which there was no substantial disagreement among raters. As a general trend, the agreement among participants was highest for stimuli close to the extremes. We also selected training stimuli for each attribute. Thus, the complete abridged set contains 96 short musical motifs to be used in future studies, in addition to 16 equivalent training motifs (2 for each pole of each of the 4 attributes): the abridged Balance subset includes 12 clearly *balanced* and 12 clearly *unbalanced* musical motifs, the abridged Contour subset includes 12 clearly *smooth* and 12 clearly *jagged* musical motifs, the abridged Symmetry subset includes 12 clearly *symmetric* and 12 clearly *asymmetric* musical motifs, and the abridged Complexity subset includes 12 clearly *simple* and 12 clearly *complex* musical motifs.

Study 2: Computational assessment of musical stimuli

This study had four main goals: (1) to develop a series of specific computational measures that provide a suitable description of each of the 200 musical motifs in terms of structural properties, (2) to derive nonredundant composite measures for each attribute, (3) to determine which of the composite measures, or combination thereof, explained participants' ratings of each attribute in Study 1, and (4) to compare the explanatory adequacy of our composite measures of complexity with existing methods. Our aim was, therefore, to find the most complete model integrating the contributions of all parameters manipulated in the design of the stimuli.

Method

Computational measures of musical attributes

We implemented several basic, conceptually irreducible, compact, and quantitative computational measures of the design parameters of each of the four attributes. Appendix B in the Supplementary Materials describes the measures in detail, and Appendix C presents the values of the computational measures for each stimulus in each corresponding subset.

Higher values correspond to more unbalance, jaggedness, asymmetry, and complexity. The measures were devised to assess each of the attributes in our MUST set, but we expect them to generalize to other stimuli, experimental paradigms, and researchers. A comprehensive description and formulation of the computational measures, together with a rationale for their selection, is presented as Appendix B in the Supplementary Materials. The corresponding functions for MATLAB integrate the MUST toolbox, available at osf.io/bfxz7 and https://github.com/compaes.

Balance As conceived here, balance is related to the distribution of events and the position of the climax in the course of a tensional process. We implemented three measures that capture three different aspects of the global perception of balance based on the distribution of events and the relative positions of each motifs' center of mass and geometric center (Table 2).

Contour Contour perception is related to the magnitude of changes in pitch and duration. Small changes are perceived as smooth, whereas large changes are perceived as abrupt or jagged. We implemented three measures of intervallic and melodic abruptness, and one measure of rhythmic abruptness (Table 2).

Symmetry The only form of symmetry considered is vertical mirror reflection: the strict retrogradation of all sounds (pitch and duration) from a central axis. Due to notation restrictions, an adjustment of the last note duration was sometimes needed (to equalize it to the first one). We implemented two measures of this kind of musical symmetry (Table 2).

Complexity The complexity of the motifs was manipulated by varying the quantity and variety of elements in pitch and duration, resulting in variations in predictability. We implemented one measure of the number of elements, and seven measures that capture different aspects related to the variety of elements and their predictability (Table 2).

Our battery of measures takes advantage of the state of the art in music information research, music cognition, and related fields, while going further in designing new measures. For instance, *event density* and *pitch entropy* are common in existing models of perceived complexity, such as Eerola et al.'s Expectancy-Violation model (EV; Eerola, 2016). However, Eerola and colleagues based their analysis on pitch classes, whereas we consider absolute pitch, and our measures of entropy of pitches go beyond pitch entropy in considering, for example, the entropy of tuples and intervals (see Appendix B). Some measures include an application of established principles and algorithms correspondingly cited (e.g., Shannon entropy, Parncutt's model), while other measures are entirely original (e.g., Symmetry measures).

To determine whether variation in the parameters pertaining to each attribute actually contribute to variation in that attribute and not—or not significantly—to variation in the other three attributes, we also applied the full battery of measures detailed in Table 2 to the 200 musical motifs. The results indicate that the manipulations of parameters pertaining to any given attribute did not result in notable effects on other attributes. This analysis is reported in Appendix D.

Composite nonredundant measures

Given that the measures described above capture different aspects (e.g., *melodic abruptness* and *durational abruptness*)

Table 2 Computational measures of the parameters used to compose musical motifs varying in Balance, Contour, Symmetry, and Complexity

Attribute	Parameter	Computational measure
Balance	Distribution of elements/events	***Bisect unbalance***: Equilibrium between the two halves of a stimulus
	Climax position	***Center of mass offset***: Distance between center of mass and geometric center
	Tension	***Event heterogeneity***: Heterogeneity in the temporal distribution of events
Contour	Intervals	***Average absolute interval***: Average absolute pitch interval size
		Melodic abruptness: Average interval size of changes of direction per note
		Durational abruptness: Proportion of the stimulus with changes of direction
	Durations	***Rhythmic abruptness***: Average ratio of consecutive durations
Symmetry	Vertical mirror structure	***Total asymmetry***: Direct–retrograde accumulated pitch difference
		Asymmetry index: Proportion of the stimulus with asymmetries
Complexity	Number of elements/events	***Event density***: Number of note events per time unit
	Variety of elements/events	***Average local pitch entropy***: Average pitch entropy of .25-s sliding windows
	Predictability	***Pitch entropy***: Entropy of pitch distribution
		2-tuple pitch entropy: Entropy of 2-tuple pitch distribution
		3-tuple pitch entropy: Entropy of 3-tuple pitch distribution
		2-tuple interval entropy: Entropy of 2-tuple interval distribution
		3-tuple duration entropy: Entropy of 3-tuple duration distribution
		Weighted permutation entropy: Permutation entropy considering the *SD* of the pitch distribution of each 3-note sequence

of the same attribute (e.g., contour), we expected multiple regression models to contain some redundancy and multicollinearity. Therefore, we conducted four principal components analyses (PCA), one for each attribute, in order to extract nonredundant components for each attribute. We then used these components as predictors of participants' ratings.

Before running the PCA, several tests were conducted to evaluate the adequacy of the data for factor analysis. Bartlett's test of sphericity quantifies the overall significance of all correlations within the correlation matrix ($p < .050$). The Kaiser-Meyer-Olkin (KMO > .50) assesses the sampling adequacy and the strength of the relationships among variables. Values of the determinant of the correlation matrix over 10^{-5} indicate an acceptable amount of multicollinearity in the data set.

Factors were retained following Jolliffe's (eigenvalues > 0.70; Jolliffe, 1972) criterion and inspecting the cumulative proportion explained. When extracting more than one factor, *oblimin* rotation was performed, given that factors relating to the same attribute were not entirely orthogonal. We calculated the component scores for each stimulus and treated these as composite computational measures of balance, contour, symmetry, and complexity in the subsequent analyses.

Explaining participants' ratings of musical attributes

We used linear mixed-effects models (Hox, Moerbeek, & van de Schoot, 2010; Snijders & Bosker, 2012) to analyze the effects of the predictors (the composite computational measures obtained in the PCA) on participants' responses for each subset. They account simultaneously for the between-subject and within-subject effects (Baayen, Davidson, & Bates, 2008), and are thus especially suitable for responses that may vary between individuals and stimuli (Silvia, 2007; Brieber, Nadal, Leder, & Rosenberg, 2014; Cattaneo et al., 2015; Vartanian et al., 2019). We created a model for each subset to assess the predictive power of the components with respect to participants' responses. The structure of all models was the same. We modeled the behavioral ratings of balance, contour, symmetry, and complexity considering the corresponding composite measures, and their interactions when more than one, as fixed effects. We included random intercepts and slopes for the composite measures, and their interaction when more than one, within participants, following Barr, Levy, Scheepers, and Tily's (2013) recommendation to model the maximal random-effect structure. In addition to avoiding loss of power and reducing type I error, this enhances the possibility of generalizing results to other participants.

Following Aguinis, Gottfredson, and Joo (2013), and considering the nature of our study, we looked for highly influential observations among participants' ratings by inspecting Cook's distance (Cook, 1979). The threshold was set at $4/(N - k - 1)$, where N is the number of observations ($N = 43$) and k is the number of explanatory variables.

All analyses were carried out within the R environment for statistical computing, R version 3.5.1. (R Core Team, 2018). We used the *principal( )* function in the 'psych' package (Revelle, 2018), the *lmer()* function of the 'lme4' package (Bates, Maechler, Bolker, & Walker, 2015) and the 'lmerTest' package (Kuznetsova, Brockho, & Christensen, 2012) to estimate the *p*-values for the *t*-tests based on the Satterthwaite approximation for degrees of freedom, and the 'influence.ME' package (Nieuwenhuis, te Grotenhuis, & Pelzer, 2012). Effect sizes were calculated following Judd, Westfall, and Kenny's (2017) indications.

Comparison with other objective measures of complexity

We are unaware of other computational measures or models of perceived balance, contour, and symmetry that we could compare with our own. There are, however, several general models of perceived musical complexity, and we compared the performance of these models with the ability of our composite models to predict participants' complexity ratings. Order is thought to influence the perception of complexity in both domains, as discussed in Nadal et al. (2010) and Van Geert and Wagemans (2019). Besides the number and variety of events, the computational measures within the MUST complexity model (MUST$_K$) quantify various forms of entropy of sequences of pitches, intervals, and durations, thus accounting for diverse kinds of order and predictability, characteristic of the musical language. These qualities make the MUST$_K$ model suitable for comparison with models such as the expectancy-violation model or the IDyOM. For fair comparison, we only considered complete models developed at the same explanatory level and addressing the same dimension (cf., Marin & Leder, 2013). We selected three models that are suitable for short stimuli, that have been demonstrated to be the best in their respective categories, and that have been validated with Western tonal music:

FLAC compression. Free Lossless Audio Codec (FLAC) is a compression format specific for audio files (Coalson, 2008) that incorporates a linear autoregressive predictor and has been proven a good indicator of perceived musical complexity based on data redundancy (Marin & Leder, 2013). In contrast to generic systems such as ZIP, special attention is placed on the temporal organization of structures (Robinson, 1994). We employed the default settings at an online FLAC converter (https://audio.online-convert.com/). Since all WAV files had similar size (1.6 MB), we simplified computations by using compressed file size as the predictor.

Expectancy-Violation model. Eerola et al.'s expectancy-based model (EBM; Eerola & North, 2000; Eerola, Himberg, Toiviainen, & Louhivuori 2006), later renamed Expectancy-Violation model (EV; Eerola, 2016), is a feature-based model. Concretely, we used the EV$_4$ model (Eerola, 2016) with predictors: tonal ambiguity, pitch proximity, entropy of duration distribution, and entropy of pitch-class distribution. This validated instrument is in line with our design, including some of the parameters we manipulated to characterize the Complexity subset, and is thus preferred over other models such as Streich's (2007). As pointed out by Albrecht (2016), Eerola's (2016) study convincingly indicated that just a few low-level parameters could predict a relatively large portion of the variance in judgments of perceived melodic complexity. Eerola's model has been used to assess melodic complexity in several studies, such as Fiveash, McArthur, and Thompson (2018), and, more generally, musical features in Albrecht (2018).

Information Dynamics of Music model. The IDyOM (Pearce, 2005; Pearce, 2018) is a variable-order Markov model (Begleiter, El-Yaniv, & Yona, 2004; Bunton, 1997) that uses a multiple-viewpoint framework (Conklin & Witten, 1995), allowing it to combine models of different representations of the musical surface. IDyOM has been shown to accurately predict Western listeners' pitch expectations in behavioral, physiological, and EEG studies (e.g., Egermann et al., 2013; Hansen & Pearce, 2014; Omigie, Pearce, & Stewart, 2012; Omigie, Pearce, Williamson, & Stewart, 2013; Pearce, 2005; Pearce, Ruiz, Kapasi, Wiggins, & Bhattacharya, 2010), even better than static rule-based models (e.g., Narmour, 1991; Schellenberg, 1997). It has also been proved to account for expectations of the timing of melodic events (Sauvé, Sayed, Dean, & Pearce, 2018) and harmonic movement (Sears, Pearce, Spitzer, Caplin, & McAdams, 2018; Harrison & Pearce, 2018), and to simulate other psychological processes in music perception, including similarity perception (Pearce & Müllensiefen, 2017), recognition memory (Agres, Abdallah, & Pearce, 2018), phrase boundary perception (Pearce, Müllensiefen, & Wiggins, 2010), and aspects of emotional experience (Egermann et al., 2013; Gingras et al., 2016; Sauvé et al., 2018). We used the IDyOM in two configurations: first, the short-term model (STM) that learns incrementally on each stimulus independently; second, adding to the STM a long-term model (LTM) trained on a large corpus of Western tonal music (903 folk songs and chorales; datasets 1, 2, and 9 from Table 4.1 in Pearce, 2005, comprising 50,867 notes): the BOTH configuration. This incorporates a learned model of schematic musical syntax, providing a measure of complexity relative to the norms of the Western tonal musical style. Both configurations predict the pitch and onset of every note using a combined representation of melodic pitch interval and tonal scale degree (for pitch), and inter-onset interval ratio (in the case of onset).

To compare our composite computational measure of perceived complexity with the models described above (FLAC, EV$_4$, and IDyOM in its two configurations), we first conducted four linear mixed-effects models. Participants' ratings were modeled using each motif's complexity estimate produced by FLAC, EV$_4$, and IDyOM in its two configurations, as the independent variable. The design was similar to the complexity model described above. We compared the results of these models to the results of our MUST$_K$ model using likelihood ratio tests. For statistically significant differences ($p < .050$), lower Bayesian information criterion (BIC) and Akaike information criterion (AIC) indicate a better fit of one model over another.

Results

Computational measures of musical attributes

Appendix C in the Supplementary Materials collects the values of each of the computational measures and components for each of the 200 stimuli.

Composite nonredundant measures

Balance The computational measures in the Balance subset were adequate for PCA (Bartlett's: $\chi^2_{(3)} = 173.822$, $p < .001$; Overall MSA = .75, MSA $_{\textit{Bisect unbalance}}$ = .86; MSA $_{\textit{Center of mass offset}}$ = .68; MSA $_{\textit{Event heterogeneity}}$ = .74; Determinant of the correlation matrix = .025). The PCA with *oblimin* rotation indicated that the three initial Balance measures could be subsumed into a single component explaining 95% of the variance. The three measures contributed with similar high loadings (*bisect unbalance*: .95; *center of mass offset*: .98; *event heterogeneity*: .97). We calculated the component scores for each stimulus (BC1) and regarded these as their Balance scores (Table C1, Appendix C).

Contour The computational measures in the Contour subset were suitable for PCA (Bartlett's: $\chi^2_{(6)} = 135.974$, $p < .001$); Overall MSA = .70; MSA $_{\textit{Average absolute interval}}$ = .66; KMO $_{\textit{Melodic abruptness}}$ = .65; KMO $_{\textit{Durational abruptness}}$ = .85; KMO $_{\textit{Rhythmic abruptness}}$ = .64; Determinant of the correlation matrix = .055). The PCA indicated that we should extract two components according to Jolliffe's criterion (eigenvalue $_{\text{PC1}}$ = 2.79; eigenvalue $_{\text{PC2}}$ = 0.87), explaining 91% of the variance. After *oblimin* rotation, CC1 represented 71% of the explained variance and received loadings from *average absolute interval* (.99), *melodic abruptness* (.95), and *durational abruptness* (.81). *Rhythmic abruptness* corresponded to CC2 with a loading of .99. The component scores for each of the stimuli constituted their Contour (CC1 and CC2) scores (Table C2, Appendix C).

Symmetry The computational measures in the Symmetry subset were suitable for PCA (Bartlett's: $\chi^2_{(1)} = 92.403$, $p < .001$; Overall MSA = .50; MSA $_{\textit{Total asymmetry}}$ = .50; MSA $_{\textit{Asymmetry index}}$ = .50; Determinant of the correlation matrix = .143). The PCA resulted in a single component with eigenvalue 1.93, explaining 96% of variance, and comprising *total asymmetry* and *asymmetry index* with equal contributions of .98. The component score for each stimulus (SC1) represented its Symmetry score (Table C3, Appendix C).

Complexity We first checked whether the data set was adequate for PCA. The determinant of the correlation matrix was lower than 10^{-5}, meaning that there was too much redundancy in the data. Due to excessive multicollinearity, we removed variables with high correlations with other variables: *pitch entropy*, *2-tuple pitch entropy*, and *3-tuple pitch entropy*. The remaining computational measures in the Complexity subset were suitable for PCA (Bartlett's: $\chi^2_{(10)} = 246.082$, $p < .001$; Overall MSA = .73; MSA $_{\textit{Event density}}$ = .78; MSA $_{\textit{Average local pitch entropy}}$ = .75; MSA $_{\textit{2-tuple interval entropy}}$ = .71; MSA $_{\textit{3-tuple duration entropy}}$ = .65; MSA $_{\textit{Weighted permutation entropy}}$ = .68; Determinant of the correlation matrix = .005). The PCA indicated that two components should be extracted according to Jolliffe's criterion (eigenvalue $_{\text{PC1}}$ = 3.47; eigenvalue $_{\text{PC2}}$ = 1.00), explaining 89% of the variance. After *oblimin* rotation, KC1 comprised *event density* (1.00), *average local pitch entropy* (.96), *2-tuple interval entropy* (.94), and *weighted permutation entropy* (.60). These measures quantified the number of elements and pitch entropies, and accounted for 72% of the explained variance. KC2 corresponded to *3-tuple duration entropy* (.96). The component scores for each stimulus became their Complexity (KC1 and KC2) scores (Table C4, Appendix C).

Explaining participants' ratings of musical attributes

The results with the outliers included in the analysis described here are reported in Appendix E in the Supplementary Materials.

Balance After removing three participants whose ratings were highly influential according to Cook's distances, and rerunning the model, the linear mixed-effects model showed that the component calculated in the PCA reported above (BC1) was a strong predictor of participants' balance ratings ($ß = 0.925$, $t_{(38.952)} = 7.992$, $p < .001$). The effect of BC1 was medium to large ($d = 0.72$).

Contour The only participant whose Cook's distances were above the threshold was removed from the model, which was then run again. The new linear mixed-effects model of contour showed that both components resulting from the PCA were strong predictors of participants' ratings of contour (CC1: $ß = 0.774$, $t_{(41.053)} = 8.474$, $p < .001$; CC2: $ß = 0.370$, $t_{(48.123)} = 6.813$, $p < .001$). The interaction effect was also significant ($ß = -0.221$, $t_{(57.200)} = -6.298$, $p < .001$), meaning that the stronger the influence of one component on participants' ratings, the weaker the influence of the other component. CC1 had a medium to large effect ($d = 0.61$), CC2 had a small to medium effect (d = 0.29), and the CC1*CC2 interaction had a small effect (d = 0.17).

Symmetry When the highly influential participant had been removed, the linear mixed-effects model revealed that the Symmetry component (SC1) produced by the PCA was a strong predictor of participants' ratings of symmetry (ß = 0.380, $t_{(40.934)} = 5.410$, $p < .001$). The effect of SC1 was small (d = 0.24).

Complexity One participant highly influenced the model, and was therefore removed. The resulting linear mixed-effects model revealed that both components resulting from the PCA were strong predictors of participants' complexity ratings, KC1 (ß = 1.183, $t_{(41.409)} = 30.729$, $p < .001$) and KC2 (ß = 0.140, $t_{(45.394)} = 5.322$, $p < .001$). In addition, a mutually enhancing interaction between components was also significant (ß = 0.139, $t_{(116.995)} =$ 5.991, $p < .001$). KC1 had a very large effect (d = 1.26), KC2 had a small effect (d = 0.15), and so did the KC1*KC2 interaction (d = 0.15).

Comparison with existing models of perceived complexity

The four new linear mixed-effects models showed that other existing models of musical complexity were also good predictors of participants' complexity ratings (Table 3). However, the ANOVA mixed model likelihood ratio tests showed that our model provided a better fit to the data than all but one of the extant complexity models. Although the IDyOM STM provided a better fit to the data than our MUST$_K$ model according to AIC and BIC, the difference was not statistically significant (Table 4).

Table 3 Linear mixed-effects models of complexity for the Complexity subset

Model	Component	ß	*df*	*t*-value	*p*-value	*d*
MUST$_K$	KC1	1.18	41.41	30.729	< .001	1.26
	KC2	0.14	45.39	5.322	< .001	0.15
	KC1*KC2	0.139	116.995	5.991	< .001	0.15
FLAC		0.999	40.391	39.41	< .001	0.94
EV$_4$		1.106	41.179	37.81	< .001	1.16
IDyOM (STM)		1.146	40.828	39.71	< .001	1.27
IDyOM (BOTH)		1.074	40.691	37.25	< .001	1.09

Note: The models of perceived complexity compared here are the MUST$_K$ model, FLAC compression size, the Expectancy-Violation model with four predictors (EV$_4$), and the Information Dynamics of Music model (IDyOM) in the short-term (STM) and BOTH configurations. ß refers to the estimated slope, *df* to the degrees of freedom, and *d* to the effect size

Table 4 ANOVA mixed model likelihood ratio tests of comparisons with the MUST$_K$ model

Model	*df*	AIC	BIC	logLik	$\chi^2_{(9)}$	*p*
MUST$_K$	*15*	*4986.5*	*5069.7*	*−2478.2*		
FLAC	6	5526.3	5559.5	−2757.1	557.76	< .001
EV$_4$	6	5058.6	5091.9	−2523.3	90.127	< .001
IDyOM (STM)	6	4829.3	4862.5	−2408.6	0	1
IDyOM (BOTH)	6	5214.0	5247.3	−2601.0	245.53	< .001

Note: The models of perceived complexity compared here are the MUST$_K$ model, FLAC compression size, the Expectancy-Violation model with four predictors (EV$_4$), and the Information Dynamics of Music model (IDyOM) in the short-term (STM) and BOTH configurations. The table shows the degrees of freedom (*df*), the Akaike information criterion (AIC), the Bayesian information criterion (BIC), the log likelihood (logLik), and the *p*-value for each model comparison. The chi-squared value (χ^2) for each particular model involved 9 degrees of freedom for all models compared

Discussion

This second study focused on the structural features of the 200 musical motifs we created. We had four main goals. The first was to devise a series of computational measures providing objective descriptions of the parameters manipulated in the composition of the motifs. This led us to develop three measures of balance, four measures of contour, three measures of symmetry, and eight measures of complexity. They can be used for diverse purposes in conjunction with our stimulus set or applied to other musical motifs.

The computational measures were designed to capture aspects of the same attribute, so they were bound to include a certain degree of redundancy and multicollinearity. Our second goal was thus to derive nonredundant composite measures for each of the four attributes using principal component analyses (PCA). The results of the PCA for balance revealed that the three measures loaded highly on a single component (BC1), indicating that, in our Balance subset, the three parameters (distribution of elements/events, climax position, tension) work together to create different degrees of balance and unbalance. The composite of the three measures, calculated as the component score, constitutes each of the musical motifs' Balance score. The PCA for contour revealed two components underlying the computational measures (CC1 and CC2). The three measures of intervallic and melodic abruptness loaded onto one component (CC1), and the measure of rhythmic abruptness loaded onto another (CC2), thus mirroring the two parameters used to compose the motifs in the Contour subset, and provide the musical motifs' Contour scores. The PCA for symmetry subsumed both computational measures into a single component (SC1), in accordance with our manipulation of a single aspect of symmetry: vertical mirror structure. The composite of both measures, calculated as the component score, is each motif's Symmetry score. Finally, the PCA for complexity revealed two components underlying the computational measures (KC1 and KC2): The first was related to the number of elements, and variety and predictability of pitches, whereas the second was related to the variety and predictability of durations, thus reflecting the aspects underlying variations in the complexity of the motifs in the Complexity subset, and constitute the motifs' Complexity scores.

Our third goal was to examine the extent to which the composite measures, or combination thereof, explained participants' ratings in Study 1. The linear mixed-effects models for each attribute showed that the composite measures were strong predictors of perceived balance (BC1), contour (CC1 and CC2), symmetry (SC1), and complexity (KC1 and KC2). The results also revealed an interaction between the Contour components (CC1 and CC2), meaning that, while both individually serve as predictors of perceived musical smoothness or jaggedness, when one component (e.g., intervallic and melodic abruptness) exerts a higher influence on participants' ratings, the effect of the other (e.g., rhythmic abruptness) becomes smaller. There was also an interaction between the Complexity components (KC1 and KC2). In this case, there was a mutual enhancement: when one component (e.g., number and variety of events) exerts a stronger influence on participants' ratings, so does the other (e.g., number and variety of durations), contributing to musical complexity in complementarily reinforcing ways.

A closer look at the relations between the design and the assessments may help to understand the processes involved in the perception of these attributes in music, enabling comparison with other sensory modalities. The results suggest that our balance measures indeed captured the tensional processes and temporal discourse of the motifs, which in turn seem largely responsible for the perception of musical balance. Likewise, both pitch and rhythm correspondences between the halves of the motif appear equally relevant for the perception of musical symmetry. A different pattern emerged for perceived contour: The results suggest that an enhanced salience of either pitch (CC1) or rhythm (CC2) relations due to a pronounced abruptness reduces the prominence of the other dimension. In contrast, for complexity, the quantity and variety of elements together with pitch-related order or structure (KC1), and rhythm-related order or structure (KC2) reinforce each other in their impact on perceived musical complexity. As the most salient dimension in Western tonal music, pitch relations define harmony and structure rhythm, which reciprocally modulates pitch relations (Prince, 2011; Prince, Thompson, & Schmuckler 2009).

Two inversely related factors mainly account for perceived visual complexity: quantity and variety of elements, and order or structure (e.g., Gartus & Leder, 2017; Nadal et al., 2010). They also constitute the core of perceived complexity in music, and their interrelations in the temporal and spatial dimensions deserve close attention. The various measures of entropy assessed order and structure in music, inevitably integrating variety of elements and predictability. These factors are interdependent, and the investigation of their relative contributions would require controlling for one while manipulating the other within a common idiom.

Pitch-related entropies naturally correlated with quantity of elements, the best individual predictor also in visual studies: Maximal pitch-related entropies increase with the number of elements (equivalent to *event density*, in our case)—although this relationship saturates at a certain point, as *event density* is restricted by the musical idiom: the variety of sounds is constrained, as the notes are discrete and we established a vocal pitch range. Therefore, even though there is no theoretical boundary for maximal entropy, it is, in practice, limited by the musical style. To discern the particular contributions of pitch-related entropies, controlling for *event density* would be required. In contrast, *duration entropy* (order and structure in time) is always constrained by *event density* (number of elements). The different contributions of pitch and rhythm to perceived musical complexity also respond to the combination of several factors: First, the number of different rhythmic figures is lower than that of pitches in this particular musical idiom. Second, ratios are better recognized and remembered than absolute values (Pressing, 1999; Trehub, 1985), and pattern transformation techniques are standard compositional techniques (e.g., augmentation, retrogradation), all of which limit the number of combinations appraised as different.

Testing our computational models with other musical stimuli would either strengthen or question the validity of our approach and throw light on the way humans perceive such attributes in music. This was only possible for complexity, because no comparable computational assessments of perceived musical balance, contour, and symmetry, as defined in the stimulus design, are available. The fourth goal of this study was to compare the explanatory performance of our MUST_K model with other approaches to perceived musical complexity. The four extant models we used for comparison proved to be good predictors of participants' ratings. This suggests that they all tap into the same phenomenon. However, according to the model likelihood ratio tests and under the AIC and BIC criteria, they do so to different extents. Our model predicted participants' ratings more accurately than FLAC compression, EV_4, and the BOTH configuration of the IDyOM. The STM configuration, which generates predictions after learning directly from each specific stimulus, provided the best fit to participants' complexity ratings, though not significantly better than the MUST_K model developed here.

The better fit provided by our model might not be surprising, taking into account that it addresses precisely the design features of the musical motifs in the Complexity subset. Nevertheless, it is worth noting some differences between the parameters included in these models. The superiority over the EV_4 model can be explained by the motifs' common idiom that might have lessened the effect of EV_4's first component (*tonal ambiguity*), but also by a more comprehensive design and better performance of our measures—e.g., EV_4 considers pitch-class instead of absolute pitch, which ignores the contribution of pitch height across different octaves to perceived complexity. Investigating whether this applies to other musical stimuli would shed light on the factors underlying perceived musical complexity.

The comparisons with the FLAC and IDyOM models are especially noteworthy. A higher predictive capacity over the FLAC general-purpose audio compression algorithm may be due to the encoding of high-level symbolic features that are specific to the musical language in our model compared with the raw audio input for FLAC (sampled at 44,100 Hz with a bit depth of 16). Elucidating whether our model's superiority generalizes to other musical stimuli would shed some light on the processing of musical complexity: If our model surpassed FLAC's prediction power with other music beyond the present stimulus set, the perception of musical complexity would be driven by the combination of irreducible, basic musical features. If this were not the case, the implication would be that musical complexity is holistically appraised using general-purpose perceptual processes.

Regarding the IDyOM models, the fact that the simulation of participants' musical background worsens the short-term model may seem striking. However, it is perhaps not surprising that the BOTH model does less well than the STM and the $MUST_K$ model, because the stimuli are stylistically coherent, and complexity does not vary as a function of distance from Western tonal stylistic norms. This means that the BOTH configuration addresses the issue of context or previous experience not as a framework in which to discriminate degrees of complexity, but as a form of averaged reference from which to detect deviations. On the other hand, the $MUST_K$ model employs features crafted with knowledge of the stimulus design and was fitted to the perceptual responses to the stimuli, whereas the IDyOM complexity measures were generated entirely without prior knowledge of either the stimulus set itself or the perceptual complexity ratings for these stimuli. However, the STM learns directly from the stimulus, and thus the adaptation to the stimulus set may be similar. But more importantly, the $MUST_K$ model is based on low-level musical parameters, less computationally demanding than the STM, and thus more parsimonious. Therefore, the lack of significant differences in predictive power between these two models supports the validity of our approach and suggests that the processing of musical complexity relies on isolable basic features as those captured by the $MUST_K$ model. Further research with other stimuli will elucidate whether the present results generalize to the perceived complexity of any music.

General Discussion

Choosing among alternative options and courses of action is one of the most basic functions of cognition. Understanding cognition, therefore, requires understanding the processes involved in the valuation and comparison of alternatives. There are several reasons why music constitutes a rich domain for studying general mechanisms of valuation: Music provides a rich and virtually unlimited set of materials and is highly valued among people. But it also affords an investigation of the interaction between domain-specific and domain-general processes in valuation. The overarching goal of the research presented in this paper was to stimulate research on modality-general attributes and domain-general processes in the appreciation of music. We set out (1) to create a set of musical stimuli suitable for studying the role of modality-general attributes in music, (2) to assess the stimuli behaviorally and computationally, (3) to analyze how both kinds of assessments relate to each other, the stimulus design features, and other available measures, and (4) to make the MUST set and computational measures in the form of a MATLAB toolbox freely available to other researchers.

The design of the four subsets responds to a modality-general characterization of balance, contour, symmetry, and complexity: We distilled the essence of three sets of visual stimuli (Wilson & Chatterjee, 2005, for balance; Bertamini et al., 2016, for contour; and Jacobsen & Höfel, 2002, for symmetry and complexity) and formulated analogous musical definitions for each attribute. We restricted the design to a common idiom that makes the motifs comparable to the emulated visual stimuli and allows contrasting the target attributes across different musical examples.

Our stimuli and computational measures contribute to the investigation of perceived musical balance, contour, and symmetry in music, and further explore perceived musical complexity. Whereas the existing literature on musical complexity is comparable to that in the visual domain, a small number of studies address musical symmetry (e.g., Balch, 1981; Bianchi et al., 2017; Krumhansl et al., 1987; Mongoven & Carbon, 2017), while others investigate musical contour (e.g., Gerardi & Gerken, 1995; Schmuckler, 2015; Thorpe, 1986; Trehub et al., 1984). To the best of our knowledge, our research pioneers the study of musical balance as conceived here, and our modality-general characterization of these four attributes within a coherent set and toolbox is a unique contribution.

The MUST set combines ecological validity and experimental control, a delicate and desirable balance between two core virtues of any set of stimuli. The results demonstrated that the set is sensitive to nonmusicians' abilities to detect degrees of musical balance, complexity, contour, and symmetry (cf., Petrović, et al., 2017), accurately captured by the computational measures: Participants' consistent judgments matched the stimulus design and were largely explained by our composite models. Furthermore, the comparisons with extant models of musical complexity support ours as an outstanding approach. The coherence between design and assessments strengthens the value of the set and the computational measures as reliable open resources for research. First, its virtues make the set highly useful in empirical aesthetics and other fields, especially in its abridged form and when the interest is musical–visual correspondence. Second, the measures contribute new tools to music information research because they may easily be applied to other stimuli. Ultimately, investigating the relations between the stimulus design, their behavioral appraisal, and the computational measures may contribute to further understanding of musical and psychological processes.

The MUST stimuli and computational measures may be useful in multiple settings and fields, together or separately: First, the subsets may be used together, addressing several attributes or individually focusing on one of them, and the motifs can be assessed in other ways. Indeed, the design of other assessments is feasible and desirable, especially regarding the less studied attributes. Second, while the measures perfectly complement the stimuli, their general character and reliable performance in predicting participants' judgments make them suitable for other purposes and musical stimuli as well, even if small adaptations were needed. Monophonic melodies would be particularly appropriate, especially if short, for which no specific adjustment would be required. However, testing them with longer, more varied, and naturalistic musical stimuli would be of great interest in assessing how the measures and fitted models generalize as models of music perception. To facilitate the use of the methods and materials presented here by other researchers, we have made the full and abridged stimulus set, together with the open-source package of functions as a toolbox for MATLAB, freely available for use by the scientific community at osf.io/bfxz7. The detailed description and formulation of the measures constitute Appendix B, and the values for each stimulus in each of the corresponding measures and components constitute Appendix C of the Supplementary Materials.

Authors' contributions AC created the stimuli and wrote the manuscript; AC and MV designed the computational measures; MV formalized, implemented, and wrote the measures; AC and MN designed the research, discussed the stimuli, and analyzed the data; AC, GC, GA, and MN contributed to the behavioral assessment; AC, MV, MP, and MN compared and discussed the measures, and revised the manuscript. All authors reported no conflicts of interest and approved the manuscript.

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Appendix A

Study 1: Behavioral Assessment

Questionnaire

Original Spanish version.

1. ¿Cuál es tu edad? (Respuesta numérica)
2. ¿Cuál es tu género? Mujer / Hombre / Otro
3. ¿Cuál es el nivel de estudios más alto que has completado hasta la fecha? Secundaria / Bachillerato o equivalente / Grado, licenciatura o equivalente / Posgrado, máster o doctorado
4. ¿Cuál es el nivel de estudios musicales más elevado alcanzado hasta el momento? Enseñanza general obligatoria (primaria y secundaria) / Enseñanza elemental de música (escuela de música o conservatorio elemental) / Enseñanza profesional de música (conservatorio profesional) / Grado en música Posgrado, máster o doctorado en música
5. ¿Te dedicas profesionalmente a la música? Sí / No
6. ¿Cuánto te han gustado los motivos musicales en general? Por favor, valora del 1 (muy poco) al 5 (mucho).
7. ¿Te ha resultado difícil la tarea? Sí / No
8. ¿Qué te ha costado juzgar más? Simetría / Complejidad / Equilibrio / Contorno
9. ¿Te ha llamado la atención algún otro factor que no se esté considerando? ¿Cuál?

Translated English version.

1. How old are you? (Numeric response)
2. What is your gender? Woman / Man / Other
3. What is the highest level of education you have completed? Secondary school or equivalent Preuniversitary / Undergraduate, Bachelor / Postgraduate, Masters or Ph.D. Degree
4. What is the highest level of musical education you have completed? General education (primary and secondary) / Elementary musical education (music school or conservatory) / Professional musical education (music school or conservatory) / Bachelor, Postgraduate, Masters or Ph.D. Degree in Music
5. Are you a professional musician? Yes / No
6. How much did you like the musical motifs in general? Please, rate from 1 (very little) to 5 (very much).
7. Was the task difficult? Yes / No
8. What has been more difficult to judge? Symmetry / Complexity / Balance / Contour
9. Has any other factor not considered here called your attention? ¿Which?

THE MUST SET AND TOOLBOX

Instructions to Participants

Balance

Original Spanish version.

EQUILIBRIO

Por favor, evalúa el motivo musical en función de su equilibrio, desde 1 (muy equilibrado) hasta 5 (muy desequilibrado).

Las siguientes cuestiones facilitarán la elección de la respuesta más adecuada respecto de cada motivo musical:

- Si se imagina un centro, ¿cómo se organizan los sonidos en torno a él, de forma desequilibrada o equilibrada?
- ¿Se acumulan los sonidos de forma irregular, más en un extremo que en otro (principio o final), o se distribuyen a lo largo del motivo musical (más equilibradamente)?
- ¿Da la sensación de estar bien proporcionado?
- Si percibe un clímax de tensión, ¿éste se encuentra en alguno de los extremos (más desequilibrado) o hacia el centro (más equilibrado)?

Los motivos musicales que presentamos cubren un amplio espectro de grados de equilibrio, así que no temas emplear las puntuaciones extremas si lo consideras apropiado.

Los ejemplos siguientes ilustran el concepto: observarás que *q* y *w* son más equilibrados o balanceados, mientras que en *e* y *r* el desequilibrio es mayor.

Translated English version.

BALANCE

Please, evaluate the musical motif according to its balance, from 1 (very balanced) to 5 (very unbalanced).

The following questions will facilitate the election of the most adequate response for each musical motif:

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- If you imagine a (temporal) center, how are the sounds organized around it: in an unbalanced or in a balanced way?
- Do the sounds accumulate irregularly, skewed toward one of the extremes (beginning or end), or are they distributed through the motif (more balanced)?
- Does the motif give the feeling of being well proportioned?
- If you perceive a tensional climax, is it placed towards one of the extremes or the center (more equilibrated)?

The musical motifs here presented cover a broad spectrum of balance degrees, so do not hesitate in using extreme ratings if appropriate.

The following examples illustrate the concept: you may observe that *q* and *w* are more balanced, whereas *e* and *r* are more unbalanced.

Contour

Original Spanish version.

CONTORNO

Por favor, evalúa el motivo musical en función de su contorno, desde 1 (muy suave) hasta 5 (muy abrupto).

Las siguientes cuestiones facilitarán la elección de la respuesta más adecuada respecto de cada motivo musical:

- ¿Cómo es la sensación global que le proporciona el motivo musical: suave, curva, continua, fluida, o por el contrario, abrupta, angulosa, brusca o dura?
- En general, ¿los sonidos contiguos tienen alturas próximas (el intervalo o salto que forman es pequeño, con lo que la música resultará más suave) o lejanas (el intervalo es grande, haciendo que la música resulte más abrupta)?
- ¿Los cambios rítmicos son normalmente pequeños y progresivos (suaves) o grandes y súbitos (abruptos)?

Los motivos musicales que presentamos cubren un amplio espectro de contornos, así que no temas emplear las puntuaciones extremas si lo consideras apropiado.

Los ejemplos siguientes ilustran el concepto: observarás que *q* y *w* son más suaves, mientras que *e* y *r* son más abruptos.

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Translated English version.

CONTOUR

Please, evaluate the musical motif according to its contour, from 1 (very smooth) to 5 (very jagged).

The following questions will facilitate the election of the most adequate response for each musical motif:

- How is the global feeling provided or suggested by the musical motif: smooth, soft, curved, continuous, fluid, or, on the contrary, jagged, abrupt, angled, sudden, and harsh?
- In general, do the pitches of adjacent sounds are close (i.e., the interval or jump between them is small, so that the music is softer), or distant (i.e., the interval is wide, making the music more abrupt)?
- Are the rhythmic changes usually small and progressive (smooth) or wide and sudden (abrupt)?

The musical motifs here presented cover a broad spectrum of contours, so do not hesitate in using extreme ratings if appropriate.

The following examples illustrate the concept: you may observe that *q* and *w* are smoother, whereas *e* and *r* are more jagged.

Symmetry

Original Spanish version.

SIMETRÍA

Por favor, evalúa el motivo musical en función de su simetría, desde 1 (muy simétrico) hasta 5 (muy asimétrico).

Las siguientes cuestiones facilitarán la elección de la respuesta más adecuada respecto de cada motivo musical:

- ¿Está construido en espejo, con un eje en el centro a partir del cual los sonidos se repiten en orden inverso a los de la primera parte, tipo ABCCBA?

THE MUST SET AND TOOLBOX

- ¿Coinciden el principio y el final, pero al revés?
- ¿Aparecen las mismas notas en la mitad de la pieza, pero dadas la vuelta?

Los motivos musicales que presentamos cubren un amplio espectro de niveles de simetría, así que no temas emplear las puntuaciones extremas si lo consideras apropiado.

Los ejemplos siguientes ilustran el concepto: observarás que *q* y *w* son totalmente simétricos, mientras que *e* y *r* no lo son.

Translated English version.

SYMMETRY

Please, evaluate the musical motif according to its symmetry, from 1 (very symmetric) to 5 (very asymmetric).

The following questions will facilitate the election of the most adequate response for each musical motif:

- Does the motif have mirror structure, with a central axis from which the sounds of the first half appear again in a retrograde motion, generating an ABCCBA form for the whole motif?
- Are the beginning and ending exactly reversed?
- Do the same notes appear twice but turned over in the middle of the motif?

The musical motifs here presented cover a broad spectrum of symmetry levels, so do not hesitate in using extreme ratings if appropriate.

The following examples illustrate the concept: you may observe that *q* and *w* are totally symmetric, whereas *e* and *r* are not symmetric.

Complexity

Original Spanish version.

COMPLEJIDAD

Por favor, evalúa el motivo musical en función de su complejidad, desde 1 (muy simple) hasta 5 (muy complejo).

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Las siguientes cuestiones facilitarán la elección de la respuesta más adecuada respecto de cada motivo musical:

- ¿Se suceden pocos (simple) o muchos (complejo) elementos o eventos?
- ¿Son poco (simple) o muy variados (complejo)?
- ¿Es la música completamente predecible (simple) o muy sorprendente (complejo)?
- ¿Es fácil de seguir (simple) o requiere gran esfuerzo (complejo)?

Los motivos musicales que presentamos cubren un amplio espectro de niveles de complejidad, así que no temas emplear las puntuaciones extremas si lo consideras apropiado.

Los ejemplos siguientes ilustran el concepto: observarás que *q* y *w* son más simples, mientras que *e* y *r* son más complejos.

Translated English version.

COMPLEXITY

Please, evaluate the musical motif according to its complexity, from 1 (very simple) to 5 (very complex).

The following questions will facilitate the election of the most adequate response for each musical motif:

- Do few or many elements of events occur in the motif?
- Are they little (simple) or very varied (complex)?
- Is the music very predictable (simple) or, in contrast, very surprising (complex)?
- Is it easy to follow (simple), or does it require a great effort (complex)?

The musical motifs here presented cover a broad spectrum of complexity degrees, so do not hesitate in using extreme ratings if appropriate.

The following examples illustrate the concept: you may observe that *q* and *w* are simpler, whereas *e* and *r* are more complex.

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Appendix B. Computational Measures of Musical Stimuli: The MUST Toolbox

Ana Clemente, Manel Vila-Vidal, Marcus T. Pearce, Germán Aguiló, Guido C. Corradi, and Marcos Nadal

First, the package MIDI toolbox (https://github.com/MIDItoolbox/1.1) was used to import the MIDI files into MATLAB R2018a (The MathWorks, Inc., Natick, Massachusetts, USA) and to extract the onset (in beats of 0.5 s, from the beginning), the duration (also in beats of 0.5 s), and the MIDI pitch of each note event (Eerola & Toiviainen, 2004). Given a MIDI file of length T (4 s in our case) containing a total number of N notes, each note is denoted by its position in the sequence, i, that ranges from 1 to N. Then, for a given note i, we designated its pitch, onset time, and duration, as f_i, o_i, and d_i, respectively. Thereupon, we quantified the perceptual properties of the motifs as conceived in their design. High values mean high unbalance, jaggedness, asymmetry, and complexity.

The names of the functions of the MUST toolbox for MATLAB appear next to the measure's heading. Intermediate functions are also included in the toolbox, but not directly cited in the text. Although discarded for the empirical and theoretical reasons explained below, the functions of other measures developed in the investigation are also formulated in the MUST toolbox and cited in the text.

Balance

Bisect unbalance [`biUnbalance`]

Bisect unbalance quantifies how unevenly distributed the note events are between the two halves of the stimulus. For this purpose, we take into consideration onset times and disregard durations. We first find the distance between the first and the last onset times, $\tau = o_N - o_1$. We then find the proportion of note events with onset times either before or after $\tau/2$. Let them be called F_1 and F_2, respectively. Then, *bisect unbalance* is defined as:

$$b_1 = 1 - 4F_1F_2.$$

Note that this ensures that the measure assumes values in the range $[0, 1]$, with the maximum unbalance value (1) being attained either when $F_1 = 0$ or $F_2 = 0$, and the minimum value (0) when there is a total balance between the two halves of the stimulus ($F_1 = F_2 = 0.5$).

Center of mass offset [`comOffset`]

The *center of mass offset* quantifies the distance between the temporal center of the stimulus ($\tau/2$, found as in *bisect unbalance*) and the center of mass of the distribution of note onsets across the stimulus. First, we take the average of all onset times to obtain what we call the center of mass (COM) of the stimulus. We then substract $\tau/2$ from the resulting value to find the distance between the two centers and finally divide by the total duration (τ) to obtain a normalized value. As we take the absolute value, the *center of mass offset* ranges between 0 and 1, with higher values reflecting a COM shifted further right or left from the temporal center of the stimulus. A value of exactly 0 reflects the totally balanced case in which the COM is found at the precise temporal center of the stimulus:

$$b_2 = \left| \frac{1}{\tau} \left(\frac{1}{N} \sum_{i=1}^{N} o_i - \frac{\tau}{2} \right) \right| = \left| \frac{1}{N} \sum_{i=1}^{N} \frac{o_i}{\tau} - \frac{1}{2} \right|.$$

Event heterogeneity [`eventHeterogeneity`]

This measure assesses how uniformly distributed the note events are, regardless of where the irregularities occur. First, we need to compute the local density curve. To do so, we consider sliding time windows of length $w = \alpha \frac{\tau}{N-1}$ with window step $\frac{w}{2}$ (i.e., with an overlap of 50%). Note that $\frac{\tau}{N-1}$ is the inverse of the global note onset density and, therefore, equal to the average inter-onset interval. Thus, the parameter α can be thought of as the expected number of notes per window (in our case, we used $\alpha = 2$). Then, we count the number of notes contained in each window j (with $j = 1, \cdots, J$; where J is the total number of sliding windows) and divide by the window length:

$$\delta_j = \frac{(N-1)n_j}{\alpha\tau},$$

with $n_j = \#\{\text{note events with onset time contained in window } j\}$. The local unbalance is defined as the ratio between the local density and the global density. As such, at time window j the local unbalance is simply $\frac{n_j}{\alpha}$. Segments with an accumulation (resp. depletion) of note events will have unbalance values larger (resp. smaller) than 1, which represents the case in which the local density coincides with the overall density. We finally take the standard deviation of this measure giving greater penalization to unbalanced events far from the center as compared to those close to it. The rationale behind this approach is that the accumulation of note events around the center may lead to a further release of tension that is not perceived as a lack of balance. *Event heterogeneity* is thus defined as:

$$b_3 = \frac{\sum_{j=1}^{J} \left(\frac{n_j}{\alpha} - 1\right)^2 w_j}{\sum_{j=1}^{J} w_j},$$

where the weight w_j ranges in the interval $[0, 1]$ and is the absolute time difference between the center of window j and the center of the stimulus $(\frac{\tau}{2})$ divided by $\frac{\tau}{2}$. This measure has no upper theoretical bound but, in practice, the largest value attained in the Balance subset is 1.411.

Contour

Average absolute interval [`avAbsInterval`]

This measure reflects the average absolute pitch interval on a logarithmic scale. It thus focuses on the magnitude of pitch changes between notes, one of the most prominent characteristics of a melodic profile:

$$c_1 = \frac{1}{N-1} \sum_{i=1}^{N-1} \log(|f_{i+1} - f_i| + 1).$$

The last term is incorporated to avoid values smaller than 1, for which the logarithm returns negative values. As a consequence, the minimum interval (the unison) is mapped to 0 and the output of the function monotonically increases with larger intervals. In the Contour subset, the largest value for this measure is 2.519.

Melodic abruptness [`melAbruptness`]

Melodic abruptness is a measure of intervallic sharpness, quantified as the accumulated intervallic size of changes of direction per time unit (as log-scaled intervals). To compute *melodic abruptness*, we first identify the notes where there is a change of direction (preceded by an ascending interval and followed by a descending interval, or vice versa) and define their sharpness as the average of the two surrounding intervals (log-scaled):

$$s_i = \log\left(\frac{|f_{i+1} - f_i| + |f_i - f_{i-1}|}{2} + 1\right).$$

Notes for which there is no change of direction as well as the first and the last notes of the stimulus are assigned zero sharpness. The *melodic abruptness* is then found by averaging the sharpness per time unit:

$$c_2 = \frac{1}{T} \sum_{i}^{N} s_i .$$

The largest value attained in the Contour subset is 11.387. Taking a visual metaphor, a change of melodic direction would mark the vertex, and the magnitude of the change per time unit would give the angle: the larger the intervals around a change of direction, the sharper the angle; and the greater the number of sharp changes per time unit, the more jagged the music.

Durational abruptness [`durAbruptness`]

A greater number of changes of melodic direction will create a more jagged contour (assuming the number and magnitude of intervals remain constant). *Durational abruptness* quantifies this effect as the proportion of the overall duration of the stimulus that is taken up with changes of melodic direction.

We first adjust the notes' durations so as to mimic perceptual features such as the smallest discriminable duration and the saturation of echoic memory after a certain threshold. To this end, we use Parncutt's phenomenological model, according to which the perceived "durational accent increases with IOI [inter-onset-interval] for small values of IOI and saturates as IOI approaches and exceeds the duration of the echoic store (auditory sensory memory)" (Parncutt, 1994: 427). In Parncutt's model, the durational accent is governed by the following equation:

$$\delta = \left[1 - \exp\left(\frac{d}{\theta} \right) \right]^{i} ,$$

where d is the duration of the note (in seconds), θ accounts for the saturation duration (the larger θ, the sooner saturation is reached), and i flattens the curve close to $d = 0$ so as to account for minimum discriminable durations. As proposed by Parncutt, we set $\theta = 0.5$ and $i = 2$ in our implementation of the model. In what follows, we will refer to the sequence of durational accents adjusted by this model as δ_i.

Then, the *durational abruptness* of a stimulus is simply defined as:

$$c_3 = \frac{\sum_{\text{for i with change of direction}} \delta_i}{\sum_{i=1}^{N} \delta_i} .$$

The measure is bounded in the range [0,1].

Rhythmic abruptness [`rhythmAbruptness`]

This measure quantifies the average ratio between consecutive rhythmic figures, expressed as a quotient of durations. It thus focuses on rhythmic intervals, measuring how suddenly note durations change. Durations are first adjusted according to Parncutt's saturation model. Then, we compute the duration ratio for each pair of consecutive notes with the largest duration always in the numerator so as to ensure ratios are always larger than 1: $r_i = \delta_{i+1}/\delta_i$ if $\delta_{i+1} > \delta_i$, and $r_i = \delta_i/\delta_{i+1}$, otherwise. We finally take the average of all ratios across the whole stimulus:

$$c_4 = \sum_{i=1}^{N-1} r_i.$$

The largest value of *rhythmic abruptness* in the Contour subset is 8.615.

Symmetry

Total asymmetry [`asymTotal`]

Total asymmetry measures the accumulated pitch difference between original and reversed versions of the stimulus, quantified as follows. Let T be the total duration of the stimulus, and $f(t)$, the pitch at time t for all t between 0 and T. We define the instant asymmetry as:

$$a(t) = \left| f(t) - f(T-t) \right|.$$

Finally, the *total asymmetry* is defined as the average of this function across the whole motif:

$$s_1 = \frac{1}{T}\int_0^T a(t)dt = \frac{1}{T}\int_0^T \left| f(t) - f(T-t) \right| dt.$$

The *total asymmetry* has a lower bound (0), but it can grow arbitrarily large. However, in the Symmetry subset, the largest value is 6.645.

Asymmetry index [`asymIndex`]

Asymmetry index is also defined as the average of an instant asymmetry function across the whole motif but, in this case, the instant asymmetry is simply an index function that assesses whether there is a pitch difference between the motif played forwards and backwards, thus disregarding the specific pith distance. In particular, $a(t) = 1$ if $|f(t) - f(T-t)| > 0$, and 0 otherwise. Note that the asymmetry index will always be between 0 and 1. Its magnitude can be interpreted as the proportion of the overall duration of the stimulus for which it is asymmetric.

Complexity

Event density [`eventDensity`]

The basic principle of quantity of elements can be directly assessed as the total number of note events, only when comparing monophonic motifs with the same duration, like those of the set. In order to make the measure generalizable to other musical stimuli, total length must be controlled. In consequence, the density of events emerges as a better measure than quantity. *Event density* is then defined as the number of note events in the stimulus per time unit:

$$k_1 = \frac{N}{T}.$$

In the Complexity subset, the number of note events ranges from 3 to 31, and $T = 4$ s. Thus, the values for this measure in this subset range from 0.750 to 7.750.

Average local pitch entropy [`avLocalp1entropy`]

The pitch distribution might exhibit a certain degree of disorder at the whole stimulus level, while still preserving a certain local structure. To study this local effect, one can take small sliding windows (window length = 1 s, window step = 0.25 s in our case) and locally compute the pitch entropy in each window (see the next section for a detailed description of the *pitch entropy*). The average of this measure across the whole motif quantifies the local structure of the stimulus. In the Complexity subset, the maximum attained values is 1.526.

Pitch entropy [`p1entropy`]

This measure quantifies the entropy of the stimulus' pitch distribution. It disregards relations of pitches and durations, and hence any rhythmic or melodic structure. To compute the *pitch entropy*, we first need to characterize the pitch distribution. In order to do so, we count the number of times each pitch f appears in the stimulus:

$$P(f) = \frac{\#\{f_i = f \text{ for } i = 1, \ldots, N\}}{N}.$$

Note that here we are considering absolute pitch rather than pitch classes, and therefore C4 and C5, for example, will be considered as different elements. The *pitch entropy* is then defined as:

$$k_3 = - \sum_{\text{over all pitches } f \text{ appearing in the stimulus}} P(f) \log P(f). \tag{1}$$

This measure has a lower bound of 0, which corresponds to the case where only one pitch appears in the stimulus, regardless of how many times the note is repeated. As there is no theoretical limit to the number of different pitches than can appear in the stimulus, *pitch entropy* has no upper bound. In the Complexity subset, the maximum attained value is 2.316.

2-tuple pitch entropy [`p2entropy`]

2-tuple pitch entropy quantifies the entropy of the distribution of pairs of consecutive note pitches (i.e., a zeroth-order distribution of pairs of consecutive pitches). As with the *pitch entropy*, we first need to characterize the distribution of 2-note sequences (2-tuple pitch distribution henceforth). The probability of the pitch sequence (f, f') that appears at least once in the stimulus is defined as follows:

$$P((f, f')) = \frac{\#\{(f_i, f_{i+1}) = (f, f') \text{ for } i = 1, \ldots, N-1\}}{N-1},$$

where in the numerator we scan the whole stimulus for the tuple (f, f'), and every time there is a match we sum one unit for that sequence. Finally, the *2-tuple pitch entropy* is defined as the entropy of the 2-tuple pitch distribution. The maximum *2-tuple pitch entropy* attained in the Complexity subset is 3.063.

3-tuple pitch entropy [`p3entropy`]

This measure refers to the entropy of the distribution of sequences of 3 consecutive notes (i.e., pitches) or 3-tuple (f, f', f''). Similarly as before, we first define the 3-tuple pitch distribution as follows:

$$P((f, f', f'')) = \frac{\#\{(f_i, f_{i+1}, f_{i+2}) = (f, f', f'') \text{ for } i = 1, \ldots, N-2\}}{N-2},$$

and compute the entropy of this distribution. The maximum 3-tuple pitch entropy attained in the Complexity subset is 3.193.

2-tuple interval entropy [`i2entropy`]

The previous entropy measures reflect the degree of disorder of individual notes or groups of notes. However, research has shown that listeners represent melodies in memory in terms of more abstract representations of relative pitch structure such as melodic pitch interval (Dowling & Bartlett, 1981; Trehub, 1985). Therefore, it appears logic to transcend the pitch level and look at intervals. Indeed, we seem to perceive music in the most structured way possible (Snyder, 2009), attending to grouping principles (Bregman, 1990; Deutsch, 2013). We thus started by computing *interval entropy* [`i1entropy`], a more structured way to examine the entropy of 2-tuple distributions than *2-tuple pitch entropy.* However, the Pearson correlation with the behavioral assessment of musical complexity was markedly weaker ($r_p = .65$, $p < .05$) than that of 2-tuple pitch entropy ($r_p = .82$, $p < .001$). We therefore chose *2-tuple pitch entropy* for pitch distributions of 2 consecutive pitches over *interval entropy.*

Because melodic cells often contain more than 2 pitches, we addressed the entropy of sequences of 3 consecutive pitches. Indeed, *3-tuple pitch entropy* already comprises *pitch entropy*, *2-tuple pitch entropy*, and *interval entropy.* And *2-tuple interval entropy* is a more structured way of considering the entropy of tuples of 3 consecutive pitches. It measures the entropy of the distribution of sequences of 2 consecutive intervals. It is thus similar to *3-tuple pitch entropy* but differs in that sequences of 3 notes obtained from the same intervallic sequences are grouped together. Therefore, if the sequences C-D-E and G-A-B are considered two different elements in the 3-tuple pitch distribution, they are seen as the concatenation of two ascending major seconds in the 2-tuple interval distribution. To compute this, we first find the 3-tuple pitch distribution and collapse pitch tuplets that are obtained from the same sequence of intervals:

$$P(\bar{I}, \bar{I'}) = \sum_{(f,f',f'') \text{ if } f+I=f' \text{ and } f'+I'=f''} P((f, f', f'')).$$

Then, we compute the entropy of this distribution. The maximum *2-tuple interval entropy* attained in the Complexity subset is 3.075. In motifs of duration, musical idiom, and methodological constraints like ours, sequences of more than 3 elements would be rare or not applicable to an important number of stimuli in the Complexity subset.

3-tuple duration entropy [`d3entropy`]

Regarding time structure, we followed the rationale applied to pitch distributions: We computed the entropy of single duration, of 2-tuple duration, and of 3-tuple duration distributions. As expected, the entropy of single durations [`d1entropy`] did not significantly correlate with perceived complexity ($p < .05$). This obeys to the restricted number of different durations (much more limited than that of pitches, especially in motifs like ours), and to the nature of the musical idiom and music perception (Pressing, 1999; Trehub, 1985). We therefore aimed to explore the existence of recursive rhythmical patterns across the stimulus. In musical motifs of short duration like these, the possibilities of imitative resources such as augmentation are limited. On the contrary, literal repetitions of rhythmic patterns are easier to implement and recognize, and help to apprehend the meter. Such patterns are typically formed by 2 or 3 rhythmic figures (e.g., medieval rhythmic modes). Therefore, we started by computing the entropy of 2-tuple duration distribution `[d2entropy]`. The Pearson correlation coefficients with the behavioral assessment resulted non-significant ($p > .05$), indicating that rhythmic sequences of two consecutive durations did not impact the perception of musical complexity in the Complexity subset, and we thus discarded this measure. The other possibility was to assess the entropy of sequences of 3 consecutive durations `[d3entropy]`. Now, the Pearson's r was significant ($p < .001$) and the entropy of 3-tuple duration distribution was included as a computational measure of perceived musical complexity.

As with all previous entropy-based measures, we first find the 3-tuple duration distribution by identifying all 3-note durational sequences appearing in the stimulus. Once the distribution is defined, computing the entropy is a straightforward operation (see equation 1). This measure has no theoretical upper bound but, in the Complexity subset, the maximum attained value is 2.185.

Weighted permutation entropy [`wpEntropy`]

Another way to assess the pitch complexity of the stimulus is to compute its permutation entropy, a measure that was initially designed to quantify the tendency to repeat ascending or descending n-element patterns (typically, $n = 3$) within arbitrary time series (Bandt & Pompe, 2002). The permutation entropy is computed as the Shannon entropy of the distribution of order patterns of a time series. It thus takes into account only the order of the elements in the time series (whether there are ascents or descents) regardless of their absolute magnitude.

When sequences of $n = 3$ different elements are considered, six possible permutation patterns emerge: 123, 132, 213, 231, 312, and 321. However, when working with melodies, we should also account for pitch repetitions. This gives a total of 13 order signatures: the six permutations of three different elements (123, 132, 213, 231, 312, 321), the six possibilities with only two different pitches (122, 211, 112, 221, 121, 212) and one case in which all three elements have the same pitch (111).

Each order signature can represent different 3-element sequences, all of which, however, share a common ascending and descending pattern. Some examples should clarify how this association is performed: C4-D4-E4, C4-E4-F4, E4-G4-C5, and any sequence of strictly ascending pitches would correspond to the first pattern (123). The second pattern (132), on the other hand, represents any sequence in which the second pitch is higher than the first one, while the third one lies in between the first and the second one (e.g., C4-E4-D4, C4-B4-F4, G4-G5-C5). For the case of only two different pitches, the pattern 122, for example, represents any ascending interval followed by the repetition of the second pitch (e.g., C4-E4-E4, G5-C6-C6), while 212 represents any descending interval followed by the initial pitch (e.g., C4-B3-C4, G5-C5-G5). The last case (111) represents any sequence of three repeated pitches (e.g., C4-C4-C4, E5-E5-E5). As such, any 3-note sequence can be associated with a pitch order signature.

Then, the probability of a particular pitch order signature is computed as the number of times the order signature appears in the stimulus divided by the total number of 3-note groups in the stimulus ($N-2$). For an order signature σ:

$$P(\sigma) = \frac{\#\{\text{pitch sequences } (f_i, f_{i+1}, f_{i+2}) \text{ with order signature } \sigma\}}{N-2}.$$

Once the probability distribution is found, the computation of the entropy is done as in equation 1 above. However, when computing the permutation entropy of a stimulus, two sequences of notes with equal permutation signature but different intervallic magnitude (C4-D4-E4 vs. C4-F4-B4) will have an equal impact on the computation of the permutation probabilities. A way to correct for this is to weight the effect of each 3-note sequence using the standard deviation of their pitch distribution (Fadlallah, Chen, Keil, & Príncipe, 2013; Xia, Shang, Wang, & Shi, 2016). In the case of the *weighted permutation entropy*, the following change is introduced: Each time the permutation signature is matched, we add the standard deviation of the pitch of the 3-note group (instead of 1), thus giving more weight to those groups where the intervals are larger:

$$P(\sigma) = \frac{\sum_{\text{for } (f_i,, f_{i+1}, f_{i+2}) \text{ with order signature } \sigma} SD(f_i, f_{i+1}, f_{i+2})}{N-2},$$

where SD stands for standard deviation.

The difference between the normal and the weighted version of the permutation entropy does not rely on the computation of the entropy from the probability distribution, but rather on the way the probability distribution is computed from the stimulus. As an example, imagine the sequence of notes C4-E4-G4-F4 (MIDI number: 60-64-67-65). When we use the unweighted version, we would say that the first three notes (C4-E4-G4) have an order signature of 123, while the second group (E4-G4-F4) has a permutation signature of 132. We have two of the 13 possible pitch order patterns, and each of them appears once, so they both have a probability of 0.5. However, in this particular case, the appearance of 123 is perceptually more salient with respect to 132, because C4-E4-G4 is perceived stronger or clearer than E4-F4-G4 due to their different intervallic magnitudes. The weighting accounts for this effect, as probabilities of appearance are corrected with the standard deviation of the pitch magnitudes. In the example, probabilities of encountering 132 or 123 are weighted as follows: The first three notes have permutation signature of 123 with a standard deviation of their pitches of 3.5, while the second group has a permutation signature of 132 with a standard deviation of their pitches of 1.5. Thus, we will assign probabilities of 0.7 and 0.3 to 123 and 132, respectively. The largest *weighted permutation entropy* attained in the Complexity subset is 2.178.

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Appendix C

Computational Scores of the MUST Set

Table C1. *Computational Values and Balance Scores of the MUST Balance Subset*

Motif	***Bisect unbalance***	***Center of mass offset***	***Event heterogeneity***	**BC1**
B1	**0.004**	**0.016**	**0**	**-0.998**
B2	0	0	0.143	-0.943
B3	**0.001**	**0**	**0**	**-1.061**
B4	**0.001**	**0**	**0**	**-1.061**
B5	*0*	*0*	*0*	*-1.062*
B6	0	0.004	0.063	-0.997
B7	**0**	**0.016**	**0.250**	**-0.796**
B8	**0.020**	**0.012**	**0**	**-0.987**
B9	0.001	0	0	-1.061
B10	*0*	*0*	*0.161*	*-0.929*
B11	0.003	0.011	0.117	-0.920
B12	**0**	**0**	**0**	**-1.062**
B13	**0**	**0.008**	**0.141**	**-0.916**
B14	**0.003**	**0.019**	**0.132**	**-0.879**
B15	0.063	0.036	0.083	-0.764
B16	0	0	0.158	-0.930
B17	**0**	**0**	**0.094**	**-0.984**
B18	0.049	0.052	0.359	-0.496
B19	**0.004**	**0**	**0**	**-1.055**
B20	0.008	0.021	0.194	-0.809
B21	0	0	0.106	-0.974
B22	0	0.010	0	-1.024
B23	**0**	**0.014**	**0.156**	**-0.880**
B24	0.250	0.083	0.292	-0.123

Motif	***Bisect unbalance***	***Center of mass offset***	***Event heterogeneity***	**BC1**
B25	**0**	**0.013**	**0.125**	**-0.909**
B26	**0.640**	**0.220**	**1.031**	**1.604**
B27	0.290	0.177	0.614	0.552
B28	0.250	0.202	0.708	0.662
B29	0.309	0.151	1.107	0.896
B30	0.360	0.113	0.813	0.590
B31	**0.391**	**0.169**	**0.875**	**0.896**
B32	**0.327**	**0.184**	**0.688**	**0.695**
B33	0.250	0.154	0.525	0.331
B34	**0.444**	**0.156**	**0.825**	**0.893**
B35	**0.028**	**0.097**	**0.700**	**-0.078**
B36	*0.391*	*0.254*	*1.411*	*1.658*
B37	*0.250*	*0.222*	*0.675*	*0.707*
B38	**0.694**	**0.244**	**1.025**	**1.772**
B39	0.405	0.224	0.889	1.134
B40	0.640	0.213	0.917	1.481
B41	**0.716**	**0.239**	**1.068**	**1.823**
B42	0.082	0.083	0.729	-0.021
B43	**0.360**	**0.250**	**1.156**	**1.382**
B44	0.360	0.196	0.938	1.002
B45	**0.250**	**0.210**	**0.750**	**0.726**
B46	**0.250**	**0.202**	**1.025**	**0.926**
B47	0.605	0.238	1.071	1.649
B48	0.218	0.187	0.596	0.460
B49	**0.148**	**0.151**	**0.682**	**0.292**
B50	**0.360**	**0.153**	**0.635**	**0.589**

Note. Selection of stimuli for the abridged set (bold) and the practice (italics) in the Balance subset:
Balanced = [B1, B12, B13, B14, B17, B19, B23, B25, B3, B4, B7, B8]
Unbalanced = [B26, B31, B32, B34, B35, B38, B41, B43, B45, B46, B49, B50]
Practice = [B5, B10, B37, B36]

Table C2. *Computational Values and Contour Scores of the MUST Contour Subset*

Motif	***Average absolute interval***	***Melodic abruptness***	***Durational abruptness***	***Rhythmic abruptness***	**CC1**	**CC2**
C1	2.006	7.579	0.680	1.343	1.369	-0.318
C2	**1.549**	**4.723**	**0.609**	**8.024**	**0.436**	**3.844**
C3	**1.857**	**3.479**	**0.380**	**2.459**	**0.245**	**0.121**
C4	2.514	8.736	0.625	1.344	1.812	-0.532
C5	**2.510**	**11.237**	**0.766**	**8.615**	**2.213**	**4.054**
C6	2.092	3.741	0.620	1.408	0.875	-0.367
C7	**1.898**	**6.134**	**0.401**	**1.220**	**0.653**	**-0.628**
C8	*1.224*	*4.059*	*0.456*	*4.222*	*-0.081*	*1.475*
C9	**2.242**	**8.424**	**0.750**	**1.372**	**1.770**	**-0.308**
C10	1.300	3.611	0.670	1.924	0.318	0.250
C11	1.490	6.455	0.438	1.137	0.436	-0.513
C12	2.501	5.859	0.500	1.450	1.247	-0.586
C13	**1.285**	**3.550**	**0.427**	**1.136**	**-0.088**	**-0.460**
C14	1.912	6.504	0.618	1.782	1.058	-0.080
C15	**1.813**	**4.504**	**0.417**	**1.186**	**0.419**	**-0.608**
C16	1.583	4.638	0.480	1.320	0.358	-0.391
C17	1.825	4.776	0.677	3.484	0.849	1.044
C18	1.609	5.688	0.628	4.625	0.690	1.765
C19	2.519	7.185	0.572	1.178	1.544	-0.687
C20	**1.638**	**6.838**	**0.479**	**2.136**	**0.649**	**0.091**
C21	**1.865**	**6.524**	**0.692**	**2.454**	**1.135**	**0.417**
C22	**1.592**	**4.550**	**0.370**	**1.490**	**0.169**	**-0.396**
C23	**2.229**	**7.754**	**0.583**	**1.419**	**1.402**	**-0.435**
C24	*1.378*	*5.393*	*0.500*	*4.694*	*0.262*	*1.757*
C25	**2.347**	**11.387**	**0.500**	**1.410**	**1.792**	**-0.555**
C26	**0.997**	**0.549**	**0.188**	**1.769**	**-1.081**	**-0.214**
C27	**1.295**	**0.689**	**0.313**	**1.484**	**-0.621**	**-0.364**

Motif	*Average absolute interval*	*Melodic abruptness*	*Durational abruptness*	*Rhythmic abruptness*	CC1	CC2
C28	*0.983*	*0*	*0*	*1.706*	*-1.467*	*-0.430*
C29	**1.011**	**0.862**	**0.375**	**1.813**	**-0.722**	**-0.011**
C30	1.164	0.934	0.375	1.438	-0.588	-0.290
C31	0.896	0.448	0.250	1.218	-1.058	-0.459
C32	**1.214**	**0.677**	**0.250**	**1.116**	**-0.782**	**-0.623**
C33	**1.018**	**0.824**	**0.188**	**1.321**	**-1.024**	**-0.495**
C34	**1.097**	**1.171**	**0.313**	**1.315**	**-0.713**	**-0.403**
C35	1.027	0.549	0.125	1.201	-1.151	-0.632
C36	1.016	0.549	0.167	2.338	-1.110	0.107
C37	**1.249**	**2.507**	**0.583**	**2.452**	**-0.007**	**0.505**
C38	0.995	1.036	0.375	1.738	-0.712	-0.053
C39	1.027	0.761	0.313	1.380	-0.818	-0.342
C40	1.140	0.549	0.125	1.411	-1.067	-0.539
C41	1.024	0.588	0.313	1.533	-0.844	-0.247
C42	**0.974**	**0.448**	**0.125**	**1.194**	**-1.204**	**-0.619**
C43	1.164	0.275	0.125	1.048	-1.075	-0.769
C44	0.970	1.792	0.458	1.867	-0.505	0.115
C45	**0.963**	**1.171**	**0.438**	**1.363**	**-0.611**	**-0.211**
C46	**1.168**	**1.242**	**0.250**	**1.201**	**-0.751**	**-0.556**
C47	*0.963*	*0.448*	*0.313*	*1.823*	*-0.913*	*-0.051*
C48	0.940	0.934	0.313	1.105	-0.859	-0.482
C49	**1.196**	**0.660**	**0.188**	**1.638**	**-0.911**	**-0.358**
C50	**1.039**	**0.520**	**0.250**	**1.173**	**-0.938**	**-0.532**

Note. Selection of stimuli for the abridged set (bold) and the practice (italics) in the Contour subset:
Smooth = [C26, C27, C29, C32, C33, C34, C37, C42, C45, C46, C49, C50]
Jagged = [C13, C15, C2, C20, C21, C22, C23, C25, C3, C5, C7, C9]
Practice = [C28, C47, C8, C24]

Table C3. *Computational Values and Symmetry Scores of the MUST Symmetry Subset*

Motif	***Total asymmetry***	***Asymmetry index***	**SC1**
S1	0	0	-0.861
S2	*0*	*0*	*-0.861*
S3	*0*	*0*	*-0.861*
S4	**0**	**0**	**-0.861**
S5	**0**	**0**	**-0.861**
S6	0	0	-0.861
S7	0.057	0.025	-0.814
S8	**0.0114**	**0.006**	**-0.851**
S9	**0**	**0**	**-0.861**
S10	**0**	**0**	**-0.861**
S11	**0.098**	**0.030**	**-0.796**
S12	0.098	0.028	-0.798
S13	**0.038**	**0.020**	**-0.825**
S14	**0**	**0**	**-0.861**
S15	0	0	-0.861
S16	**0**	**0**	**-0.861**
S17	0.055	0.015	-0.827
S18	**0**	**0**	**-0.861**
S19	0	0	-0.861
S20	0	0	-0.861
S21	**0**	**0**	**-0.861**
S22	**0**	**0**	**-0.861**
S23	0	0	-0.861
S24	0	0	-0.861
S25	0	0	-0.861
S26	0.500	0.250	-0.399
S27	**2.308**	**0.769**	**0.763**
S28	0.688	0.338	-0.234

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Motif	***Total asymmetry***	***Asymmetry index***	**SC1**
S29	1.769	0.615	0.418
S30	**3.308**	**0.846**	**1.128**
S31	*1.448*	*0.483*	*0.158*
S32	*4.933*	*0.933*	*1.672*
S33	5.800	0.867	1.812
S34	**2.717**	**0.769**	**0.871**
S35	3.333	0.800	1.074
S36	6.645	0.968	2.168
S37	**4.000**	**0.923**	**1.412**
S38	0.933	0.400	-0.087
S39	**3.357**	**0.786**	**1.061**
S40	**4.667**	**1.000**	**1.690**
S41	1.290	0.387	-0.010
S42	**4.133**	**0.867**	**1.373**
S43	1.448	0.552	0.249
S44	**2.606**	**0.909**	**1.026**
S45	**3.015**	**0.821**	**1.018**
S46	**6.000**	**0.828**	**1.813**
S47	**4.563**	**0.875**	**1.497**
S48	1.750	0.688	0.508
S49	**2.121**	**0.485**	**0.338**
S50	1.161	0.387	-0.044

Note. Selection of stimuli for the abridged set (bold) and the practice (italics) in the Symmetry subset:
Symmetric = [S10, S11, S13, S14, S16, S18, S21, S22, S4, S5, S8, S9]
Asymmetric = [S27, S30, S34, S37, S39, S40, S42, S44, S45, S46, S47, S49]
Practice = [S3, S2, S32, S31]

Table C4. *Computational Values and Complexity Scores of the MUST Complexity Subset*

Motif	***Event density***	***Average local pitch entropy***	***Pitch entropy***	***2-tuple pitch entropy***	***3-tuple pitch entropy***	***2-tuple interval entropy***	***3-tuple duration entropy***	***Weighted permut. entropy***	**KC1**	**KC2**
K1	**0.750**	**0.126**	**0.637**	**0.693**	**0**	**0**	**0**	**0**	**-2.893**	**-2.145**
K2	**1.250**	**0.415**	**1.055**	**1.386**	**1.099**	**1.099**	**0.693**	**0.999**	**-1.718**	**-0.574**
K3	**1.000**	**0.107**	**0.693**	**1.099**	**0.693**	**0.693**	**0**	**0.693**	**-2.265**	**-1.476**
K4	**1.250**	**0.217**	**1.055**	**1.386**	**1.099**	**1.099**	**0.693**	**1.083**	**-1.840**	**-0.472**
K5	**1.750**	**0.491**	**1.352**	**1.792**	**1.609**	**1.609**	**1.089**	**1.002**	**-1.371**	**-0.218**
K6	**1.500**	**0.260**	**1.099**	**1.609**	**1.386**	**1.386**	**1.085**	**1.323**	**-1.561**	**0.109**
K7	**1.750**	**0.545**	**1.352**	**1.792**	**1.609**	**1.609**	**0**	**1.022**	**-1.243**	**-1.231**
K8	**2.000**	**0.545**	**1.386**	**1.946**	**1.792**	**1.792**	**0**	**1.622**	**-0.867**	**-0.694**
K9	**1.250**	**0.277**	**1.055**	**1.386**	**1.099**	**1.099**	**0.693**	**1.050**	**-1.806**	**-0.510**
K10	**2.750**	**0.813**	**1.516**	**2.025**	**2.043**	**2.043**	**1.377**	**1.663**	**-0.493**	**0.548**
K11	4.250	1.203	1.855	2.773	2.708	2.708	1.590	1.458	0.268	0.407
K12	**2.750**	**0.813**	**1.516**	**2.025**	**2.043**	**2.043**	**0**	**2.008**	**-0.251**	**-0.432**
K13	*2.750*	*0.856*	*1.516*	*2.025*	*2.043*	*1.831*	*1.782*	*1.547*	*-0.631*	*0.799*
K14	3.750	0.901	1.691	2.168	2.352	1.992	2.140	1.290	-0.485	0.801
K15	2.750	0.845	1.594	2.303	2.197	2.197	2.075	1.345	-0.583	0.923
K16	*3.250*	*1.022*	*1.925*	*2.485*	*2.398*	*2.146*	*1.605*	*1.601*	*-0.238*	*0.634*
K17	4.750	1.039	1.649	2.370	2.589	2.589	2.182	1.960	0.342	1.380
K18	4.750	1.257	1.795	2.582	2.589	2.589	0	1.239	0.364	-1.361
K19	**1.500**	**0.217**	**1.099**	**1.609**	**1.386**	**1.386**	**0**	**1.384**	**-1.493**	**-0.851**
K20	5.500	1.184	1.894	2.979	2.996	2.996	1.566	2.178	0.903	0.937
K21	5.250	1.291	1.806	2.580	2.580	2.379	1.939	1.269	0.260	0.416
K22	5.250	1.303	1.897	2.718	2.871	2.871	1.784	1.879	0.757	0.869
K23	4.750	1.330	1.996	2.890	2.833	2.670	1.791	1.619	0.492	0.670
K24	5.000	1.219	2.025	2.653	2.659	2.505	0.677	1.873	0.560	-0.172
K25	4.750	1.241	1.718	2.370	2.589	2.589	1.791	1.938	0.520	0.967
K26	5.250	1.080	1.618	2.441	2.653	2.653	0.693	1.316	0.323	-0.664
K27	**5.250**	**1.371**	**2.120**	**2.718**	**2.799**	**2.507**	**2.170**	**1.415**	**0.425**	**0.768**

Motif	*Event density*	*Average local pitch entropy*	*Pitch entropy*	*2-tuple pitch entropy*	*3-tuple pitch entropy*	*2-tuple interval entropy*	*3-tuple duration entropy*	*Weighted permut. entropy*	**KC1**	**KC2**
K28	5.250	1.341	2.252	2.857	2.871	2.434	0.677	1.411	0.473	-0.644
K29	**6.250**	**1.280**	**2.068**	**2.788**	**2.955**	**2.427**	**1.598**	**1.748**	**0.672**	**0.430**
K30	4.250	0.948	1.467	2.339	2.431	2.303	2.068	1.664	-0.059	1.043
K31	*5.750*	*1.238*	*2.065*	*2.776*	*2.912*	*2.599*	*1.775*	*1.494*	*0.509*	*0.438*
K32	*5.250*	*1.309*	*1.625*	*2.528*	*2.799*	*2.799*	*2.697*	*1.852*	*0.654*	*1.697*
K33	**7.250**	**1.463**	**2.316**	**3.035**	**3.193**	**2.988**	**0**	**1.976**	**1.448**	**-0.947**
K34	**4.250**	**0.918**	**1.630**	**2.513**	**2.616**	**2.616**	**2.185**	**1.987**	**0.183**	**1.479**
K35	3.750	1.073	1.876	2.441	2.458	2.032	0	1.057	-0.278	-1.444
K36	4.750	1.289	1.850	2.736	2.833	2.507	1.792	1.714	0.427	0.750
K37	4.750	1.239	1.649	2.428	2.752	2.752	1.791	1.930	0.587	0.973
K38	4.750	1.134	1.558	2.274	2.507	2.344	1.602	1.500	0.156	0.380
K39	5.750	1.345	2.111	2.965	3.045	2.780	0	1.732	0.900	-1.012
K40	**6.250**	**1.362**	**2.068**	**3.063**	**3.075**	**3.075**	**1.595**	**1.897**	**1.088**	**0.610**
K41	**5.750**	**1.223**	**1.715**	**2.776**	**2.912**	**2.912**	**1.773**	**1.727**	**0.735**	**0.678**
K42	**5.750**	**1.285**	**2.231**	**2.839**	**2.912**	**2.780**	**2.113**	**1.903**	**0.776**	**1.141**
K43	**5.750**	**1.139**	**1.824**	**2.650**	**2.846**	**2.846**	**1.604**	**1.959**	**0.749**	**0.737**
K44	4.250	1.113	1.742	2.426	2.523	2.338	2.068	1.672	0.089	1.033
K45	5.750	1.280	1.870	2.713	2.780	2.780	0	1.403	0.710	-1.306
K46	**7.750**	**1.526**	**2.014**	**2.777**	**2.997**	**2.608**	**0**	**1.319**	**1.138**	**-1.644**
K47	**7.750**	**1.285**	**1.946**	**2.650**	**3.032**	**2.468**	**0**	**1.274**	**0.867**	**-1.667**
K48	**7.750**	**1.174**	**1.654**	**2.442**	**2.841**	**2.841**	**0**	**1.354**	**0.979**	**-1.548**
K49	**6.250**	**1.209**	**1.915**	**2.672**	**2.955**	**2.714**	**1.600**	**1.794**	**0.763**	**0.508**
K50	6.000	1.314	2.138	2.894	2.965	2.965	0	1.627	0.957	-1.116

Note. Selection of stimuli for the abridged set (bold) and the practice (italics) in the Complexity subset:

Simple = [K1, K10, K12, K19, K2, K3, K4, K5, K6, K7, K8, K9]
Complex = [K27, K29, K33, K34, K40, K41, K42, K43, K46, K47, K48, K49]
Practice = [K13, K16, K31, K32]

Appendix D

Applying all Computational Measures to all Stimuli

Aims

The main goal of our study was to create and share a set of musical stimuli that could be used to study different attributes: balance, contour, complexity, and symmetry. We therefore composed short musical motifs that varied mainly in one of those attributes. The nature of the musical language and our goal to make the stimuli as musically appealing as possible made it virtually impossible to produce variation exclusively one parameter at a time. It is, therefore, convenient to test whether the variations in the design parameters corresponding to one attribute are related mainly to variations in the other design parameters corresponding to the same attribute. This appendix reports the results of our evaluation of the design of the musical motifs according to the computational measures. We first applied the full battery of the 17 computational measures to all motifs in the four MUST subsets. Then, we carried out a Principal Component Analysis (PCA) of all the parameters measured for all the musical motifs. If the parameters load mainly onto components that match the attributes for which they were designed, and not others, we can conclude that the parameters reflect the different aspects of those attributes, and not of others.

Results

Computational assessment of the MUST motifs using all MUST computational measures

Table D1 shows the values of each computational measure for each motif in the MUST set. All values are rounded to the third decimal.

Table D1. *Stimuli Values of the Full Battery of Computational Measures*

Motif	B_u	B_cmo	B_eh	C_aai	C_ma	C_da	C_ra	S_ta	S_ai	K_ed	K_alpe	K_pe	K_2pe	K_3pe	K_2ie	K_3de	K_wpe
B1	0.004	0.016	0	1.374	39.358	0.812	1.109	3.062	0.875	7.5	1.165	1.816	3.062	3.233	2.831	0.676	1.557
B2	0	0	0.143	1.241	8.42	0.312	2.445	2.667	0.8	4	1.042	1.841	2.303	2.54	2.441	2.044	1.561
B3	0.001	0	0	2.165	62.533	0.844	1.137	4.276	0.69	7.25	1.296	2.109	2.998	3.122	3.071	0	1.291
B4	0.001	0	0	1.075	14.663	0.375	1.137	3.103	0.966	7.25	1.266	1.897	2.781	3.039	2.776	0	1.721
B5	0	0	0	1.561	19.589	0.5	1.106	3.806	0.999	5.5	1.445	2.059	2.846	2.996	2.718	0	1.751
B6	0	0.004	0.062	2.334	36.089	0.781	1.372	12	1	4.5	1.238	2.139	2.589	2.773	2.773	1.571	1.655
B7	0	0.016	0.25	1.952	30.219	0.766	7.773	2.59	0.526	4.5	1.335	2.216	2.589	2.773	2.599	1.847	1.512
B8	0.02	0.012	0	0.963	1.099	0.188	1.438	0.286	0.143	1.75	0.527	1.352	1.792	1.609	1.609	1.365	1.002
B9	0.001	0	0	1.774	48.538	0.844	1.137	3.103	0.897	7.25	1.368	1.975	2.967	3.039	2.692	0	1.318
B10	0	0	0.161	1.457	10.593	0.5	2.011	3.454	0.729	4	1.253	2.014	2.616	2.639	2.441	1.379	1.364
B11	0.003	0.011	0.117	1.032	5.781	0.37	3.501	4.974	0.958	4.25	0.963	1.921	2.773	2.708	2.119	1.931	1.789
B12	0	0	0	1.551	4.749	0.375	1	4	1	2	0.632	1.667	1.946	1.792	1.792	0	1.467
B13	0	0.008	0.141	1.236	6.356	0.281	1.898	3.933	0.733	4.5	1.223	2.11	2.833	2.773	2.48	1.922	1.332
B14	0.003	0.019	0.132	1.081	6.269	0.281	1.75	1.935	0.774	4.75	1.176	2.014	2.659	2.752	2.395	2.158	1.387
B15	0.062	0.036	0.083	1.097	1.099	0.188	1.727	4.375	1	2	0.596	1.733	1.946	1.792	1.792	1.601	0.947
B16	0	0	0.158	1.626	26.726	0.412	1.133	5.475	0.911	8	1.618	2.169	2.763	3.078	2.838	0	1.27
B17	0	0	0.094	1.276	3.519	0.281	1.167	5.273	0.727	2.5	0.741	1.973	2.197	2.079	2.079	1.375	1.292
B18	0.049	0.052	0.359	1.296	8.166	0.312	1.555	3.375	0.75	4.5	1.196	2.043	2.833	2.773	2.361	1.853	1.671
B19	0.004	0	0	1.249	8.33	0.375	1.062	3.867	0.667	3.75	1.213	1.899	2.54	2.565	2.352	0	1.58
B20	0.008	0.021	0.194	0.884	3.178	0.406	2.953	1.056	0.889	2.75	0.813	1.468	1.834	2.043	2.043	1.93	1.354

Motif	B_u	B_cmo	B_eh	C_aai	C_ma	C_da	C_ra	S_ta	S_ai	K_ed	K_alpe	K_pe	K_2pe	K_3pe	K_2ie	K_3de	K_wpe
B21	0	0	0.106	1.048	19.713	0.531	1.41	3.419	0.774	7	1.294	2.016	2.885	3.045	2.865	1.374	1.974
B22	0	0.01	0	0.915	3.932	0.188	2.771	4	0.875	4	0.83	1.576	2.431	2.54	2.441	1.788	1.727
B23	0	0.014	0.156	1.181	4.277	0.5	1.637	3.867	0.8	2.5	0.751	1.696	2.043	2.079	2.079	1.925	1.451
B24	0.25	0.083	0.292	1.082	2.351	0.188	1.331	2.25	0.625	2	0.556	1.494	1.748	1.792	1.792	1.363	1.251
B25	0	0.013	0.125	1.217	7.303	0.25	1.596	4	0.867	4	1.174	1.981	2.708	2.639	2.441	1.923	1.516
B26	0.64	0.22	1.031	1.352	4.03	0.062	1.603	4.286	0.667	2.5	0.775	2.025	2.197	2.079	2.079	0.683	1.21
B27	0.29	0.177	0.614	1.361	7.17	0.281	1.445	5.333	0.833	3.25	0.678	1.992	2.485	2.398	2.272	1.639	1.514
B28	0.25	0.202	0.708	1.209	6.091	0.208	1.862	2.731	0.819	2	0.508	1.667	1.946	1.792	1.792	1.589	1.449
B29	0.309	0.151	1.107	1.591	5.989	0.125	2.445	2.818	0.636	2.25	0.741	1.735	2.079	1.946	1.946	1.59	1.494
B30	0.36	0.112	0.812	1.345	4.924	0.161	3.418	2.846	0.538	2.5	0.973	1.557	1.735	1.733	1.733	1.784	1.116
B31	0.391	0.169	0.875	1.315	10.163	0.703	4.913	3.499	0.787	4	0.984	1.841	2.708	2.639	2.305	1.682	1.619
B32	0.327	0.184	0.688	1.555	5.193	0.469	1.505	7.034	0.828	3.5	1.074	2.305	2.458	2.485	2.485	1.752	1.2
B33	0.25	0.154	0.525	1.396	4.836	0.271	3.721	4.183	0.901	3	0.909	1.979	2.272	2.303	2.164	1.853	1.263
B34	0.444	0.156	0.825	1.323	9.85	0.531	1.76	2.37	0.741	3	0.826	1.82	2.098	2.303	2.025	1.086	1.083
B35	0.028	0.097	0.7	0.951	1.872	0.062	1.934	2.25	0.438	3	0.585	1.979	2.398	2.303	1.834	1.711	1.233
B36	0.391	0.254	1.411	1.462	5.704	0.25	1.891	3.131	0.888	4	1.046	2.101	2.616	2.639	2.342	1.17	1.216
B37	0.25	0.222	0.675	1.708	11.037	0.604	1.881	10.099	0.912	3	0.462	2.138	2.398	2.303	2.303	1.675	1.427
B38	0.694	0.244	1.025	1.065	1.504	0.062	1.628	10.455	1	3	0.847	2.369	2.398	2.303	1.28	1.258	0.457
B39	0.405	0.224	0.889	1.185	4.549	0.219	1.496	2.048	0.381	2.75	0.418	1.846	2.164	2.197	2.043	1.429	1.482
B40	0.64	0.212	0.917	1.429	6.628	0.104	1.605	3.26	0.867	5	1.072	2.155	2.726	2.813	2.736	0.677	1.124
B41	0.716	0.239	1.068	1.414	7.838	0.625	1.285	2.345	0.759	3.25	0.974	1.839	2.485	2.398	2.398	1.048	1.454

Motif	B_u	B_cmo	B_eh	C_aai	C_ma	C_da	C_ra	S_ta	S_ai	K_ed	K_alpe	K_pe	K_2pe	K_3pe	K_2ie	K_3de	K_wpe
B42	0.082	0.083	0.729	1.548	10.834	0.271	3.432	4.763	0.812	3.5	0.991	2.243	2.352	2.485	2.369	1.818	1.478
B43	0.36	0.25	1.156	0.95	2.485	0.167	2.327	1.869	0.838	2.5	0.584	1.696	2.043	2.079	1.906	1.259	1.215
B44	0.36	0.196	0.938	1.131	2.603	0.062	2.136	5.517	0.759	2.5	0.566	2.025	2.197	2.079	1.667	1.776	0.994
B45	0.25	0.21	0.75	1.457	4.394	0.208	2.387	2.17	0.793	3	0.791	2.023	2.398	2.303	2.303	2.169	1.189
B46	0.25	0.202	1.025	1.58	5.976	0.196	4.694	3.586	0.828	3	0.701	2.023	2.398	2.303	2.303	1.896	1.245
B47	0.605	0.238	1.071	0.759	0	0	1.661	0.69	0.207	2.25	0.537	1.427	1.667	1.748	1.748	1.593	0.962
B48	0.218	0.187	0.596	1.295	9.018	0.188	2.191	1.143	0.333	3.75	0.847	1.864	2.54	2.565	2.352	1.598	1.625
B49	0.148	0.151	0.682	1.83	13.654	0.719	2.223	5.379	0.759	3.25	0.843	2.352	2.485	2.398	2.398	1.453	1.442
B50	0.36	0.153	0.635	2.02	23.19	0.656	2.146	5.44	0.88	3.75	1.117	2.303	2.639	2.565	2.565	1.084	1.446
C1	0.136	0.095	0.147	2.006	30.315	0.68	1.343	4.529	0.647	4.75	1.241	2.406	2.89	2.833	2.833	2.052	1.556
C2	0.017	0.015	0.321	1.549	18.891	0.609	8.024	4.592	0.73	5.75	1.355	2.306	3.028	3.045	2.846	1.384	1.678
C3	0.003	0.012	0.074	1.857	13.914	0.38	2.459	10.121	0.788	4.75	1.293	2.132	2.736	2.833	2.833	2.37	1.443
C4	0.01	0.014	0.125	2.514	34.945	0.625	1.344	12.472	0.906	5	1.181	2.112	2.726	2.89	2.813	1.372	1.787
C5	0.033	0.02	0.325	2.51	44.946	0.766	8.615	12.909	0.938	5.5	1.452	2.665	2.979	2.996	2.996	2.814	1.528
C6	0	0.014	0.062	2.092	14.963	0.62	1.408	6	0.933	2.5	0.795	2.164	2.197	2.079	2.079	1.385	1.511
C7	0.034	0.047	0.08	1.898	24.537	0.401	1.219	7.375	0.75	6.75	1.442	2.282	3.098	3.219	3.163	1.554	1.601
C8	0.002	0.01	0.208	1.224	16.235	0.456	4.222	4.983	0.874	6.25	1.61	2.324	2.889	3.015	2.894	2.347	1.073
C9	0	0.015	0.109	2.242	33.697	0.75	1.372	10.125	1	4.5	1.194	2.322	2.833	2.773	2.426	1.584	1.586
C10	0.04	0.11	0.071	1.3	14.442	0.67	1.924	1.419	0.387	3.75	1.262	1.956	2.639	2.565	2.565	2.277	1.806
C11	0.001	0	0	1.49	25.819	0.438	1.137	3.862	0.828	7.25	1.532	2.189	3.066	3.193	3	0	1.094
C12	0.25	0.066	0.275	2.501	23.437	0.5	1.449	5.214	0.429	3	0.853	1.907	2.398	2.303	2.303	2.054	1.685

Motif	B_u	B_cmo	B_eh	C_aai	C_ma	C_da	C_ra	S_ta	S_ai	K_ed	K_alpe	K_pe	K_2pe	K_3pe	K_2ie	K_3de	K_wpe
C13	0.002	0	0.141	1.285	14.201	0.427	1.136	4.968	0.839	6.25	1.375	2.103	2.889	3.075	2.872	1.748	1.578
C14	0.09	0.077	0.208	1.912	26.016	0.618	1.782	6.438	0.938	5	1.329	2.181	2.771	2.89	2.736	2.122	1.491
C15	0.04	0.031	0.222	1.813	18.014	0.417	1.186	6.133	0.867	5	1.412	2.346	2.799	2.89	2.736	1.583	1.623
C16	0.002	0.004	0.286	1.583	18.554	0.48	1.32	8.061	0.97	5.75	1.283	2.341	2.839	3.045	2.979	1.916	1.745
C17	0	0.013	0.141	1.825	19.102	0.677	3.484	5.375	0.875	4.5	1.233	2.197	2.67	2.686	2.599	2.376	1.524
C18	0.02	0.035	0.25	1.609	22.75	0.628	4.625	4.219	0.826	5.25	1.472	2.384	2.996	2.944	2.726	2.474	1.726
C19	0	0	0	2.519	28.742	0.572	1.178	11.875	0.875	4	1.187	2.393	2.708	2.639	2.639	0	1.454
C20	0.005	0.002	0.067	1.638	27.352	0.479	2.135	8.75	1	7	1.225	2.206	3.039	3.205	3.151	2.352	1.745
C21	0.049	0.022	0.172	1.865	26.096	0.692	2.454	4.375	0.938	4.5	1.254	2.245	2.67	2.773	2.686	2.157	1.717
C22	0.003	0.015	0.118	1.592	18.2	0.37	1.49	6.966	0.759	4.75	1.355	2.16	2.63	2.752	2.67	1.788	1.701
C23	0.01	0.023	0.222	2.229	31.018	0.583	1.419	13.806	0.968	5	1.424	2.857	2.944	2.89	2.89	2.151	1.52
C24	0.007	0.062	0.466	1.378	21.571	0.5	4.694	4.543	0.794	6	1.391	2.207	2.955	3.091	2.776	2.378	1.652
C25	0.005	0.018	0.048	2.347	45.548	0.5	1.41	9.742	0.903	7	1.295	2.188	3.142	3.258	3.025	1.374	1.831
C26	0.111	0.065	0.071	0.997	2.197	0.188	1.769	2	0.533	2.25	0.69	1.523	2.079	1.946	1.946	1.378	1.197
C27	0	0.042	0.188	1.295	2.757	0.312	1.484	2.267	0.533	1.5	0.354	1.561	1.609	1.386	1.386	1.093	1.005
C28	0	0.01	0.125	0.983	0	0	1.706	7.333	0.8	2	0.621	2.079	1.946	1.792	1.011	1.599	0
C29	0.184	0.092	0.2	1.011	3.45	0.375	1.813	4	0.9	1.75	0.497	1.55	1.792	1.609	1.609	1.382	1.283
C30	0.02	0.012	0	1.164	3.738	0.375	1.438	1.714	0.714	1.75	0.527	1.277	1.561	1.609	1.609	1.38	1.038
C31	0.012	0	0.107	0.896	1.792	0.25	1.218	4.75	1	2.25	0.704	1.735	2.079	1.946	1.748	1.597	0.976
C32	0.111	0.056	0	1.214	2.708	0.25	1.116	3.75	0.75	1.5	0.39	1.561	1.609	1.386	1.386	0.691	1.045
C33	0.008	0.058	0.222	1.018	3.296	0.188	1.321	3.733	0.933	2.75	0.755	1.72	2.164	2.197	1.889	1.77	1.195

Motif	B_u	B_cmo	B_eh	C_aai	C_ma	C_da	C_ra	S_ta	S_ai	K_ed	K_alpe	K_pe	K_2pe	K_3pe	K_2ie	K_3de	K_wpe
C34	0.008	0	0.083	1.097	4.682	0.312	1.315	4.462	0.923	2.75	0.827	1.894	2.303	2.197	2.043	1.584	1.198
C35	0	0	0.062	1.027	2.197	0.125	1.201	3.467	0.8	3.5	1.09	1.871	2.352	2.369	2.095	1.373	1.064
C36	0.008	0.01	0.111	1.016	2.197	0.167	2.338	2.781	0.703	2.75	0.849	1.846	2.303	2.197	2.197	1.787	1.511
C37	0.028	0.019	0.05	1.249	10.029	0.583	2.452	2.414	0.604	3	0.95	1.561	2.02	2.025	2.025	1.599	1.723
C38	0.04	0.008	0.094	0.995	4.143	0.375	1.738	2.923	0.769	2.5	0.769	1.505	2.043	2.079	2.079	1.593	1.624
C39	0	0.023	0.188	1.027	3.045	0.312	1.38	3.714	0.714	2.5	0.82	1.887	2.197	2.079	1.906	1.562	1.006
C40	0.062	0.062	0.083	1.14	2.197	0.125	1.411	4.286	0.857	2	0.589	1.667	1.946	1.792	1.792	1.607	1.068
C41	0	0.021	0.167	1.024	2.351	0.312	1.533	2.308	0.615	2	0.603	1.56	1.55	1.561	1.561	1.354	0.844
C42	0.02	0.057	0.167	0.974	1.792	0.125	1.194	6.375	1	3.5	1.065	1.97	2.245	2.254	1.748	0.68	0.814
C43	0.02	0	0	1.164	1.099	0.125	1.048	1.429	0.571	1.75	0.545	1.55	1.792	1.609	1.609	0	0.929
C44	0.016	0.036	0.143	0.97	7.167	0.458	1.867	1.103	0.588	4	0.958	1.7	2.211	2.441	2.243	1.376	1.505
C45	0.006	0.022	0.068	0.963	4.682	0.438	1.363	1.067	0.533	3.25	0.943	1.525	2.023	2.398	2.272	1.378	1.305
C46	0	0	0.062	1.168	4.97	0.25	1.201	1.867	0.667	3.5	1.09	1.909	2.458	2.485	2.138	1.373	1.265
C47	0.02	0.024	0	0.963	1.792	0.312	1.823	2.133	0.533	1.75	0.527	1.277	1.792	1.609	1.609	1.376	1.2
C48	0	0.035	0.05	0.94	3.738	0.312	1.105	2.308	0.769	3	0.867	1.517	2.146	2.303	2.303	0.681	1.472
C49	0	0.018	0	1.196	2.639	0.188	1.638	6.118	0.941	2	0.596	1.906	1.946	1.792	1.792	1.365	1.094
C50	0	0.048	0	1.039	2.079	0.25	1.173	1.556	0.444	1.5	0.303	1.242	1.609	1.386	1.386	1.085	0.906
K1	0.111	0.083	0	2.079	2.079	0.125	1.334	0	0	0.75	0.126	0.637	0.693	0	0	0	0
K2	0.36	0.2	0.5	1.445	1.099	0.042	2.611	0.006	0.003	1.25	0.415	1.055	1.386	1.099	1.099	0.693	0.999
K3	0.25	0.1	0	0.462	0	0	1.221	0	0	1	0.107	0.693	1.099	0.693	0.693	0	0.693
K4	0.04	0.033	0	1.936	2.079	0.25	1.289	0	0	1.25	0.217	1.055	1.386	1.099	1.099	0.693	1.083

Motif	B_u	B_cmo	B_eh	C_aai	C_ma	C_da	C_ra	S_ta	S_ai	K_ed	K_alpe	K_pe	K_2pe	K_3pe	K_2ie	K_3de	K_wpe
K5	0.02	0.071	0.15	0.963	1.099	0.25	1.941	0	0	1.75	0.491	1.352	1.792	1.609	1.609	1.089	1.002
K6	0	0.013	0.062	1.743	4.503	0.375	1.083	0	0	1.5	0.26	1.099	1.609	1.386	1.386	1.085	1.323
K7	0.02	0	0	1.596	1.792	0.125	1.048	0	0	1.75	0.545	1.352	1.792	1.609	1.609	0	1.022
K8	0	0	0	0.908	2.773	0.25	1	0	0	2	0.545	1.386	1.946	1.792	1.792	0	1.622
K9	0.36	0.1	0.167	1.936	1.792	0.125	1.155	0	0	1.25	0.277	1.055	1.386	1.099	1.099	0.693	1.05
K10	0.008	0.013	0.194	1.258	6.762	0.562	1.591	0	0	2.75	0.813	1.516	2.025	2.043	2.043	1.377	1.663
K11	0.003	0.004	0.117	1.306	6.356	0.312	1.45	0	0	4.25	1.203	1.855	2.773	2.708	2.708	1.59	1.458
K12	0.008	0	0.056	1.075	8.671	0.583	1.06	0.057	0.025	2.75	0.813	1.516	2.025	2.043	2.043	0	2.008
K13	0.008	0.03	0.167	1.12	6.068	0.292	1.958	0.011	0.006	2.75	0.856	1.516	2.025	2.043	1.831	1.782	1.547
K14	0.004	0.067	0.385	1.041	5.493	0.188	2.05	0	0	3.75	0.901	1.691	2.168	2.352	1.992	2.14	1.29
K15	0.008	0.068	0.167	1.352	3.871	0.312	2.55	0	0	2.75	0.845	1.594	2.303	2.197	2.197	2.075	1.345
K16	0.006	0.008	0.114	1.248	6.29	0.25	1.481	0.098	0.03	3.25	1.022	1.925	2.485	2.398	2.146	1.605	1.601
K17	0.025	0.024	0.206	1.303	15.911	0.594	2.369	0	0	4.75	1.039	1.649	2.37	2.589	2.589	2.182	1.96
K18	0.003	0	0	1.462	7.698	0.208	1.174	0.098	0.028	4.75	1.257	1.795	2.582	2.589	2.589	0	1.239
K19	0	0	0.062	0.832	2.197	0.333	1	0.018	0.008	1.5	0.217	1.099	1.609	1.386	1.386	0	1.384
K20	0	0.014	0.138	0.995	14.951	0.375	1.361	0	0	5.5	1.184	1.894	2.979	2.996	2.996	1.566	2.178
K21	0.002	0.01	0.105	1.116	6.186	0.312	1.745	0	0	5.25	1.291	1.806	2.58	2.58	2.379	1.939	1.269
K22	0.002	0.01	0.105	1.448	16.333	0.562	1.745	0	0	5.25	1.303	1.897	2.718	2.871	2.871	1.784	1.879
K23	0.003	0.008	0.103	1.181	8.266	0.375	1.751	0	0	4.75	1.33	1.996	2.89	2.833	2.67	1.791	1.619
K24	0.01	0.043	0.056	1.312	9.833	0.25	1.23	0.055	0.015	5	1.219	2.025	2.653	2.659	2.505	0.677	1.873
K25	0.003	0.008	0.103	1.244	13.123	0.5	1.751	0	0	4.75	1.241	1.718	2.37	2.589	2.589	1.791	1.938

Motif	B_u	B_cmo	B_eh	C_aai	C_ma	C_da	C_ra	S_ta	S_ai	K_ed	K_alpe	K_pe	K_2pe	K_3pe	K_2ie	K_3de	K_wpe
K26	0.002	0.008	0	1.495	13.159	0.562	2.581	0	0	5.25	1.08	1.618	2.441	2.653	2.653	0.693	1.316
K27	0.002	0.001	0.132	0.988	7.049	0.281	3.231	0.048	0.027	5.25	1.371	2.12	2.718	2.799	2.507	2.17	1.415
K28	0.002	0.022	0	0.994	7.167	0.292	1.175	0.06	0.034	5.25	1.341	2.252	2.857	2.871	2.434	0.677	1.411
K29	0.014	0.031	0.109	1.021	11.988	0.406	1.544	0	0	6.25	1.28	2.068	2.788	2.955	2.427	1.598	1.748
K30	0.003	0.002	0.117	0.974	6.068	0.312	1.504	0	0	4.25	0.948	1.467	2.339	2.431	2.303	2.068	1.664
K31	0.002	0.011	0.107	0.914	6.782	0.281	1.742	0	0	5.75	1.238	2.065	2.776	2.912	2.599	1.775	1.494
K32	0.002	0.003	0.211	1.114	11.368	0.604	2.289	0.125	0.049	5.25	1.309	1.625	2.528	2.799	2.799	2.697	1.852
K33	0.001	0	0	1.039	12.36	0.344	1.137	0	0	7.25	1.463	2.316	3.035	3.193	2.988	0	1.976
K34	0.003	0.002	0.25	1.069	11.485	0.656	3.514	0.002	0.002	4.25	0.918	1.63	2.513	2.616	2.616	2.185	1.987
K35	0.004	0	0	0.925	2.485	0.188	1.062	0	0	3.75	1.073	1.876	2.441	2.458	2.032	0	1.057
K36	0.003	0.008	0.103	1.174	9.648	0.375	1.4	0	0	4.75	1.289	1.85	2.736	2.833	2.507	1.792	1.714
K37	0.003	0.008	0.103	1.171	12.085	0.5	1.751	0	0	4.75	1.239	1.649	2.428	2.752	2.752	1.791	1.93
K38	0.003	0.005	0.074	1.264	11.059	0.438	2.054	0	0	4.75	1.134	1.558	2.274	2.507	2.344	1.602	1.5
K39	0.002	0	0	1.327	15.331	0.458	1.061	0.115	0.037	5.75	1.345	2.111	2.965	3.045	2.78	0	1.732
K40	0.002	0.004	0.076	1.259	23.289	0.719	1.856	0	0	6.25	1.362	2.068	3.063	3.075	3.075	1.595	1.897
K41	0.002	0.009	0.131	1.087	6.068	0.281	1.503	0	0	5.75	1.223	1.715	2.776	2.912	2.912	1.773	1.727
K42	0.017	0.026	0.226	1.414	19.191	0.562	3.662	0.002	0.002	5.75	1.285	2.231	2.839	2.912	2.78	2.113	1.903
K43	0.002	0.006	0.107	0.981	8.03	0.281	2.222	0	0	5.75	1.139	1.824	2.65	2.846	2.846	1.604	1.959
K44	0.003	0.002	0.117	1.171	10.771	0.562	1.504	0	0	4.25	1.113	1.742	2.426	2.523	2.338	2.068	1.672
K45	0.002	0	0	1.396	12.668	0.375	1.061	0.117	0.037	5.75	1.28	1.87	2.713	2.78	2.78	0	1.403
K46	0.001	0	0	1.464	13.369	0.281	1.053	0	0	7.75	1.526	2.014	2.777	2.997	2.608	0	1.319

Motif	B_u	B_cmo	B_eh	C_aai	C_ma	C_da	C_ra	S_ta	S_ai	K_ed	K_alpe	K_pe	K_2pe	K_3pe	K_2ie	K_3de	K_wpe
K47	0.001	0	0	1.075	14.046	0.469	1.053	0	0	7.75	1.285	1.946	2.65	3.033	2.468	0	1.274
K48	0.001	0	0	2.004	59.879	0.906	1.053	0	0	7.75	1.174	1.654	2.442	2.841	2.841	0	1.354
K49	0.002	0.005	0.098	1.342	24.542	0.688	1.922	0	0	6.25	1.209	1.915	2.672	2.955	2.714	1.6	1.794
K50	0	0	0.08	1.503	12.583	0.333	1.003	0.19	0.045	6	1.314	2.138	2.894	2.965	2.965	0	1.627
S1	0.02	0.071	0.15	0.963	1.099	0.25	1.941	0	0	1.75	0.491	1.352	1.792	1.609	1.609	1.089	1.002
S2	0	0.013	0.062	1.743	4.503	0.375	1.083	0	0	1.5	0.26	1.099	1.609	1.386	1.386	1.085	1.323
S3	0.04	0.033	0	1.099	1.099	0.25	1.289	0	0	1.25	0.217	1.055	1.386	1.099	1.099	0.693	1.07
S4	0	0	0	0.908	2.773	0.25	1	0	0	2	0.545	1.386	1.946	1.792	1.792	0	1.622
S5	0.36	0.1	0.167	1.936	1.792	0.125	1.155	0	0	1.25	0.277	1.055	1.386	1.099	1.099	0.693	1.05
S6	0.008	0.013	0.194	1.258	6.762	0.562	1.591	0	0	2.75	0.813	1.516	2.025	2.043	2.043	1.377	1.663
S7	0.008	0	0.056	1.075	8.671	0.583	1.06	0.057	0.025	2.75	0.813	1.516	2.025	2.043	2.043	0	2.008
S8	0.008	0.03	0.167	1.12	6.068	0.292	1.958	0.011	0.006	2.75	0.856	1.516	2.025	2.043	1.831	1.782	1.547
S9	0.004	0.067	0.385	1.041	5.493	0.188	2.05	0	0	3.75	0.901	1.691	2.168	2.352	1.992	2.14	1.29
S10	0.008	0.068	0.167	1.352	3.871	0.312	2.55	0	0	2.75	0.845	1.594	2.303	2.197	2.197	2.075	1.345
S11	0.006	0.008	0.114	1.248	6.29	0.25	1.481	0.098	0.03	3.25	1.022	1.925	2.485	2.398	2.146	1.605	1.601
S12	0.003	0	0	1.462	7.698	0.208	1.174	0.098	0.028	4.75	1.257	1.795	2.582	2.589	2.589	0	1.239
S13	0	0	0	0.904	2.197	0.167	1.001	0.038	0.02	3	0.867	1.792	2.398	2.303	2.303	0	1.546
S14	0	0.014	0.138	0.995	14.951	0.375	1.361	0	0	5.5	1.184	1.894	2.979	2.996	2.996	1.566	2.178
S15	0.003	0.004	0.117	1.306	6.356	0.312	1.45	0	0	4.25	1.203	1.855	2.773	2.708	2.708	1.59	1.458
S16	0.008	0.011	0.075	1.379	14.724	0.5	1.86	0	0	5.5	1.289	1.894	2.78	2.926	2.926	1.781	1.975
S17	0.01	0.043	0.056	1.312	9.833	0.25	1.23	0.055	0.015	5	1.219	2.025	2.653	2.659	2.505	0.677	1.873

Motif	**B_u**	**B_cmo**	**B_eh**	**C_aai**	**C_ma**	**C_da**	**C_ra**	**S_ta**	**S_ai**	**K_ed**	**K_alpe**	**K_pe**	**K_2pe**	**K_3pe**	**K_2ie**	**K_3de**	**K_wpe**
S18	0.003	0.008	0.088	1.296	9.77	0.438	1.828	0	0	4.75	1.26	1.941	2.736	2.752	2.589	1.788	1.504
S19	0.002	0.008	0	1.495	13.159	0.562	2.581	0	0	5.25	1.08	1.618	2.441	2.653	2.653	0.693	1.316
S20	0.001	0	0	1.836	51.417	0.844	1.137	0	0	7.25	1.178	1.531	2.267	2.538	2.538	0	1.087
S21	0.003	0.002	0.117	0.974	6.068	0.312	1.504	0	0	4.25	0.948	1.467	2.339	2.431	2.303	2.068	1.664
S22	0.004	0	0	0.925	2.485	0.188	1.062	0	0	3.75	1.073	1.876	2.441	2.458	2.032	0	1.057
S23	0.003	0.002	0.117	1.171	10.771	0.562	1.504	0	0	4.25	1.113	1.742	2.426	2.523	2.338	2.068	1.672
S24	0.002	0.006	0.107	0.981	8.03	0.281	2.222	0	0	5.75	1.139	1.824	2.65	2.846	2.846	1.604	1.959
S25	0.001	0	0	2.004	59.879	0.906	1.053	0	0	7.75	1.174	1.654	2.442	2.841	2.841	0	1.354
S26	0.04	0.033	0	1.488	4.277	0.5	1.289	0.5	0.25	1.25	0.217	1.332	1.386	1.099	1.099	0.693	1.046
S27	0.012	0.019	0.25	1.248	3.091	0.125	1.806	2.308	0.769	2.25	0.777	1.889	1.906	1.946	1.946	1.378	1.253
S28	0	0	0.062	1.133	3.989	0.5	1	0.688	0.338	1.5	0.303	1.33	1.609	1.386	1.386	0	1.365
S29	0.006	0.01	0.159	1.031	3.296	0.219	2.296	1.769	0.615	3.25	0.976	1.738	2.254	2.398	2.02	2.173	1.178
S30	0.016	0.023	0	1.162	7.188	0.344	1.875	3.308	0.846	4	1.128	1.808	2.338	2.54	2.441	1.599	1.418
S31	0.003	0	0.35	1.048	7.69	0.594	2.843	1.448	0.483	4.25	1.029	1.712	2.187	2.523	1.934	1.939	1.345
S32	0.028	0.018	0.125	1.303	6.213	0.438	1.467	4.933	0.933	3	0.965	2.138	2.398	2.303	2.164	1.938	1.441
S33	0	0.03	0.425	1.529	6.535	0.5	2.633	5.8	0.867	3	0.993	1.907	2.146	2.303	2.303	1.747	1.449
S34	0.003	0.004	0	1.052	3.178	0.146	2.23	2.717	0.769	4.75	1.088	1.649	2.582	2.67	2.507	1.568	1.412
S35	0	0	0.062	1.133	9.465	0.562	1.201	3.333	0.8	3.5	1.04	1.834	2.458	2.485	2.485	1.373	1.629
S36	0.003	0.008	0.083	1.041	8.383	0.406	2.518	6.645	0.968	4.25	1.02	2.089	2.513	2.708	1.991	2.066	1.158
S37	0.02	0.04	0.079	1.31	14.784	0.406	1.815	4	0.923	5.25	1.116	1.687	2.441	2.58	2.288	1.377	1.579
S38	0.004	0	0	0.966	4.836	0.312	1.062	0.933	0.4	3.75	1.029	1.714	2.243	2.352	2.138	0	1.267

Motif	B_u	B_cmo	B_eh	C_aai	C_ma	C_da	C_ra	S_ta	S_ai	K_ed	K_alpe	K_pe	K_2pe	K_3pe	K_2ie	K_3de	K_wpe
S39	0.01	0.023	0.153	1.155	7.321	0.25	1.566	3.357	0.786	5	1.369	2.112	2.799	2.89	2.476	1.92	1.352
S40	0.003	0	0.05	1.453	12.69	0.406	1.252	4.667	1	4.25	1.321	2.119	2.599	2.708	2.523	1.753	1.173
S41	0.012	0.034	0.062	1.346	18.07	0.625	2.247	1.29	0.387	4.5	1.046	1.648	2.232	2.339	2.339	1.934	1.837
S42	0.01	0.016	0.097	1.446	13.757	0.406	1.545	4.133	0.867	5	1.264	2.039	2.799	2.89	2.813	1.94	1.633
S43	0.003	0.019	0.235	1.03	6.223	0.375	1.913	1.448	0.552	4.75	1.228	2.114	2.736	2.833	2.476	2.168	1.422
S44	0.006	0.018	0.136	0.92	5.647	0.281	2.225	2.606	0.909	3.25	0.802	1.525	2.254	2.398	2.272	1.768	1.765
S45	0.004	0.024	0.135	1.04	5.817	0.5	2.153	3.015	0.821	3.75	1.087	1.657	2.206	2.352	2.245	1.938	1.345
S46	0.001	0	0	1.239	11.079	0.25	1.137	6	0.828	7.25	1.383	2.062	3.066	3.193	3.142	0	1.719
S47	0	0.004	0	1.056	4.431	0.188	1.665	4.562	0.875	4	1.162	1.96	2.523	2.639	2.206	1.57	1.206
S48	0	0	0.109	1.104	6.762	0.281	1.372	1.75	0.688	4.5	1.155	1.889	2.476	2.599	2.513	1.587	1.463
S49	0.006	0.01	0.091	1.123	3.701	0.25	1.816	2.121	0.485	3.25	0.946	1.738	2.254	2.272	1.846	2.277	1.223
S50	0.001	0	0	2.179	64.421	0.906	1.053	1.161	0.387	7.75	1.2	1.689	2.535	2.776	2.776	0	1.123

Note. The names of the computational measures and corresponding parameters (column names) are as follows: *bisect unbalance* (B_u), *center of mass offset* (B_com), *event heterogeneity* (B_eh), *average absolute interval* (C_aai), m*elodic abruptness* (C_ma), *durational abruptness* (C_da), *rhythmic abruptness* (C_ra), *total asymmetry* (S_ta), *asymmetry index* (S_ai), *event density* (K_ed), *average local pitch entropy* (K_alpe), *pitch entropy* (K_pe), *2-tuple pitch entropy* (K_2pe), *3-tuple pitch entropy* (K_3pe), *2-tuple interval entropy* (K_2ie), *3-tuple duration entropy* (K_3de), *weighed permutation entropy* (K_wpe).

Principal components analysis

We first checked whether the data set was adequate for PCA. The determinant of the correlation matrix was lower than 10^{-5}, meaning that there was too much redundancy in the data. Although this indicates a high degree of multicollinearity among the parameters, we chose to proceed with the full battery of 17 parameters, given that our goal was to examine the relations among all of them. The set was suitable for PCA, according to Bartlett's test ($\chi^2_{(136)} = 4204.84$, $p < .001$), and to the Kaiser-Meyer-Olkin factor adequacy (Overall MSA = .81) (Table D2).

Table D2. *Kaiser-Meyer-Olkin Factor Adequacy for the Whole MUST Set*

Attribute	**Measured parameter**	**MSA**
Balance	*Bisect unbalance*	.78
	Center of mass offset	.74
	Event heterogeneity	.70
Contour	*Average absolute interval*	.66
	Melodic abruptness	.78
	Durational abruptness	.81
	Rhythmic abruptness	.68
Symmetry	*Total asymmetry*	.64
	Asymmetry Index	.64
Complexity	*Event density*	.86
	Average local pitch entropy	.90
	Pitch entropy	.85
	2-tuple pitch entropy	.86
	3-tuple pitch entropy	.81
	2-tuple interval entropy	.92
	3-tuple duration entropy	.63
	Weighed permutation entropy	.82

The PCA resulted in 5 components with eigenvalues over 1 (component 6 had an eigenvalue of .65). Thus, five components were extracted and *oblimin* rotated (Table D3).

Table D3. *Loadings and Proportion Explained for the* Oblimin-*rotated Principal Components of the MUST Computational Measures for all MUST Motifs*

	TC1	**TC2**	**TC3**	**TC4**	**TC5**
SS loadings	5.64	2.87	2.41	2.14	1.65
Proportion Var	0.33	0.17	0.14	0.13	0.10
Cumulative Var	0.33	0.50	0.64	0.77	0.87
Proportion Explained	0.38	0.19	0.16	0.15	0.11
Cumulative Proportion	0.38	0.58	0.74	0.89	1.00

The loadings for each computational measure (displayed in Table D4) show that the three balance parameters load together onto component 2, that the two symmetry parameters load together onto component 2, that all contour components load together onto component 3 except *rhythmic abruptness* that loads onto component 5, and that all complexity components load together onto component 1 except *3-tuple duration entropy*, which also loads onto component 5.

Table D4. *Loadings for the Principal Components Analysis of the MUST Computational Measures for all MUST Motifs*

Attribute	**Parameter**	**C1**	**C2**	**C3**	**C4**	**C5**
Balance	*Bisect unbalance*	-0.03	**0.97**	0.03	-0.03	-0.13
	Center of mass offset	-0.06	**0.96**	0.00	-0.01	0.00
	Event heterogeneity	0.10	**0.94**	-0.05	-0.01	0.16
Contour	*Average absolute interval*	-0.12	0.09	**0.87**	0.24	-0.04
	Melodic abruptness	0.27	-0.04	**0.81**	0.02	-0.11
	Durational abruptness	0.10	-0.14	**0.81**	-0.13	0.19
	Rhythmic abruptness	-0.08	0.11	0.21	-0.02	**0.81**
Symmetry	*Total asymmetry*	0.04	-0.02	0.20	**0.89**	0.06
	Asymmetry index	0.03	0.00	-0.04	**0.90**	0.06
Complexity	*Event density*	**0.88**	-0.04	0.17	-0.12	-0.17
	Average local pitch entropy	**0.92**	-0.11	0.00	0.03	0.00
	Pitch entropy	**0.77**	0.12	-0.04	0.44	0.06
	2-tuple pitch entropy	**0.99**	0.02	-0.04	0.07	0.01
	3-tuple pitch entropy	**1.00**	0.00	-0.02	0.01	0.02
	2-tuple interval entropy	**0.92**	-0.01	0.11	-0.07	0.05
	3-tuple duration entropy	0.04	-0.03	-0.17	0.14	**0.84**
	Weighed permutation entropy	**0.55**	-0.09	0.09	-0.39	0.31

Discussion

We conducted a Principal Component Analysis of the 17 parameters measuring the set of 200 musical motifs. With this analysis, we hoped to show that variation in the parameters intended to measure one attribute did not reflect on other attributes. That is to say, for instance, that the three balance parameters would load mainly onto a common component, and not onto a component reflecting the complexity attribute. If the parameters loaded onto components that reflect their proper attribute, we could conclude that, for the whole set of musical motifs, they indeed reflect aspects of the corresponding attribute. If, on the contrary, the parameters loaded onto components that have nothing to do with the four attributes, or onto more than one attribute, we would have to conclude that the stimuli were not appropriately designed.

The results of the PCA show that the variation in the whole set of stimuli in the 17 parameters can be reduced to 5 components. Four of them match our design attributes, and the other includes *rhythmic abruptness* and *3-tuple duration entropy*, i.e., the computational measures capturing the rhythmic aspects of Contour and Complexity, respectively. Two main conclusions can be drawn from these results: First, in the MUST set, the parameters reflecting rhythmic aspects of contour and complexity seem to be vary together, in line with research showing that frequency and time structures are processed independently (e.g., Peretz & Coltheart, 2003; Peretz & Zatorre, 2005). Second, the parameters covariate within attributes. In other words, they loaded fundamentally onto components reflecting their proper attribute and not others, effectively reflecting aspects of the same attribute. These results show, therefore, that variation in the parameters that were intended to measure a given attribute did not reflect on other attributes. This indicates that the musical motifs were well designed overall, and that the MUST set is coherent and accurately captured by the computational measures.

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Appendix E

Linear Mixed Effects Models with Outliers

Table E1. *Participants' Responses Predicted by the MUST Computational Components*

Subset	Component	ß	*t*-value	*p*-value
Balance	**BC1**	0.783	5.812	< .001
Contour	**CC1**	0.751	8.149	< .001
	CC2	0.352	6.313	< .001
	CC1*CC2	-0.209	-5.748	< .001
Symmetry	**SC1**	0.373	5.409	< .001
Complexity	**KC1**	1.183	31.483	< .001
	KC2	0.121	3.719	< .001
	KC1*KC2	0.136	5.852	< .001

Table E2. *Linear Mixed-effects Models of Complexity for the Complexity Subset*

Model	Component	ß	*t*-value	*p*-value
MUST$_K$	KC1	1.183	31.483	< .001
	KC2	0.121	3.719	< .001
	KC1*KC2	0.136	5.852	< .001
FLAC		0.996	39.12	< .001
EV$_4$		0.705	37.97	< .001
IDyOM (STM)		1.140	39.40	< .001
IDyOM (BOTH)		1.071	37.90	< .001

Table E3. *ANOVA Mixed Model Likelihood Ratio Tests of Comparisons with the MUST$_K$ Model*

Model	*df*	AIC	BIC	logLik	$\chi^2_{(9)}$	*p*-value
MUST$_K$	*15*	*5214.5*	*5298.0*	*-2592.2*		
FLAC	6	5742.3	5775.7	-2865.2	545.82	< .001
EV$_4$	6	5296.8	5330.2	-2642.4	100.31	< .001
IDyOM (STM)	6	5085.1	5118.5	-2536.5	0	1
IDyOM (BOTH)	6	5440.1	5473.6	-2714.1	243.65	< .001

VIII

Musical Aesthetic Sensitivity

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Musical Aesthetic Sensitivity

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Empirical aesthetics has mainly focused on general and simple relations between stimulus features and aesthetic appreciation. Consequently, to explain why people differ so much in what they like and prefer continues to be a challenge for the field. One possible reason is that people differ in their aesthetic sensitivity, that is, the extent to which they weigh certain stimulus features. Studies have shown that people vary substantially in their aesthetic sensitivities to visual balance, contour, symmetry, and complexity and that this variation explains why people like different things. Our goal here was to extend this line of research to music and examine aesthetic sensitivity to musical balance, contour, symmetry, and complexity. Forty-eight nonmusicians rated their liking for 96 4-s Western tonal musical motifs, arranged in four subsets varying in balance, contour, symmetry, or complexity. We used linear mixed-effects models to estimate individual differences in the extent to which each musical attribute determined their liking. The results showed that participants differed remarkably in the extent to which their liking was explained by musical balance, contour, symmetry, and complexity. Furthermore, a retest after 2 weeks showed that this measure of aesthetic sensitivity is reliable and suggests that aesthetic sensitivity is a stable personal trait. Finally, cluster analyses revealed that participants divided into two groups with different aesthetic sensitivity profiles, which were also largely stable over time. These results shed light on aesthetic sensitivity to musical content and are discussed in relation to comparable existing research in empirical aesthetics.

Keywords: aesthetic sensitivity, aesthetics, liking, music, sensory valuation

What are the laws that govern the relations between the physical and the mental? Fechner (1860) was convinced that this question could be answered by probing the quantitative relations between stimulus magnitude and sensation magnitude. He believed, however, that sensation could not be measured directly, so he developed indirect measures of the stimulus values necessary to produce differences in sensation. Although sensation itself could not be measured, differences in sensation could: People could notice whether a sensation was present or absent, or that one sensation was greater than, equal to, or smaller than another (Boring, 1950). Differential sensitivity was, thus, central to psychophysics.

Empirical aesthetics was, in its origin and essence, applied psychophysics. Fechner used empirical aesthetics to tackle the problems of aesthetics in the same way he had used psychophysics to tackle the mind–body problem (Murphy, 1929): to identify the lawful manner in which the mind translates stimulus properties into appreciation. The sensations of beauty and pleasantness could not be measured directly, so he devised methods to quantify how changes in the magnitude of stimulation produced changes in the magnitude of beauty and pleasantness. In the early days of empirical aesthetics, researchers assembled diverse sets of materials and developed new paradigms to explore how variations in certain aspects of stimuli lead to variations in appreciation. Differences in line orientation, length, curvature, thickness (Martin, 1906), proportion (Angier, 1903; Davis, 1933; Haines & Davies, 1904), polygon complexity (Beebe-Center & Pratt, 1937), level of curvature (Lundholm, 1921), symmetry (Pierce, 1894), or uniformity of figure and arrangement (Otis, 1918) led to differences in perceived beauty or pleasantness.

More than a century of research in empirical aesthetics confirms that people generally prefer symmetry to asymmetry (Gartus & Leder, 2013; Jacobsen & Höfel, 2001; Pecchinenda et al., 2014), complexity to simplicity (Machado et al., 2015; Nadal et al., 2010), and curved to angular contours (Bertamini et al., 2016; Corradi et al., 2020; Gómez-Puerto et al., 2018; Palumbo et al., 2015).

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Most of these preferences seem to transcend cultural boundaries (Che et al., 2018) and even species boundaries (Munar et al., 2015), but they also seem to be modulated by personality, familiarity, expertise, and experimental task (Cotter et al., 2017; Leder et al., 2019; Marin & Leder, 2018; Palumbo & Bertamini, 2016; Pecchinenda et al., 2014; Vartanian et al., 2019; Weichselbaum et al., 2018).

It was noted early on, however, that these general relations between stimulus features and aesthetic responses coexisted with important individual differences. Clark et al. (1913) used the concept *affective sensitiveness* to distinguish between people who strongly tended to like and dislike materials of different sorts, including tones, colors, and speech sounds, from people who were relatively indifferent to those materials (Babbitt et al., 1915). Washburn et al. (1923) showed that poets were more affectively sensitive than science students, meaning that affective sensitiveness was related to experience and expertise in art and aesthetics. Clark et al.'s (1913) concept of affective sensitiveness captures differences in the magnitude of people's response to visual and auditory stimuli, but their materials were not designed to include increments along a specific dimension. Thus, affective sensitiveness does not relate the increase in response to the increase in stimulation. It is a measure of how responsive people are to certain materials but not of how responsive they are to variations in specific features of those materials.

Corradi et al. (2019, 2020) have recently proposed a conceptualization of *aesthetic sensitivity* intended to capture differences among people in the extent to which aesthetic appreciation depends on, and is explained by, variations in specific stimulus features. It is a measure of the degree to which variations in a given feature influence someone's aesthetic appreciation. In this sense, someone is aesthetically sensitive to complexity, for instance, if their aesthetic appreciation of an object varies as a function of its complexity: for example, they like complex designs more than simple ones, or vice versa. Conversely, someone is aesthetically insensitive to complexity if this feature is irrelevant to their aesthetic appreciation: their liking is indifferent to complexity.

In this regard, aesthetic sensitivity is not equivalent to perceptual sensitivity: it does not gauge whether participants can discriminate fine variations in complexity, for instance. It is also not a measure of receptiveness to artistry—to artful execution or artistic excellence. Aesthetics and art are, to some extent, overlapping fields, although not identical (Brown & Dissanayake, 2009; Pearce et al., 2016). According to Corradi et al. (2019, 2020), aesthetic sensitivity is the extent to which variations in a particular stimulus property lead to variations in an individual's liking for the stimulus.

Corradi et al. (2019, 2020) were not the first to put forward a definition of aesthetic sensitivity. For instance, Meier (1928) defined aesthetic sensitivity as "the ability to recognize compositional excellence in representative art-situations, or the ability to 'sense' quality (beauty?) in an aesthetic organization" (Meier, 1928; p. 185). Eysenck conceived aesthetic sensitivity as a distinct ability that (a) enabled some people to appreciate objective beauty better than others ("[this ability], independently of intelligence and personality, determines the degree of good or bad taste"; Eysenck, 1983; p. 231); (b) explained performance on virtually all measures of artistic ability ("it covers a large number of, probably all, pictorial tests"; Eysenck, 1940; p. 100); and (c) was immutable because it was biologically determined, innate ("[it] presumably [has] a genetic foundation in the structure of the nervous system"; Götz et al., 1979; p. 801), and unalterable through experience ("[it] is independent of teaching, tradition, and other irrelevant associations"; Eysenck, 1940; p. 102). Parker (1978) defined musical aesthetic sensitivity as a person's biologically based competence of making value judgments in agreement with a consensus of musical sophisticates on the appropriateness to society's aesthetic values. According to this notion, to demonstrate good taste, an individual must prefer what others had judged to be more beautiful.

Corradi et al.'s (2019, 2020) conception of aesthetic sensitivity, which we apply to the music domain in this study, differs in several regards from previous conceptions of aesthetic sensitivity (Eysenck, 1940; Meier, 1928; Myszkowski et al., 2018). First, unlike Eysenck's (1983) or Meier's (1928) notion, it does not rely on the assumption that aesthetic value is an attribute of objects: Under our conception of aesthetic sensitivity, aesthetic value is a quality of the experience of objects. Second, unlike Götz et al.'s (1979) or Parker's (1978) notion, there is no external normative standard set by any authority: Aesthetic sensitivity is the extent to which sensory features influence someone's valuation. Third, unlike Eysenck's (1940) or Meier's (1928) conception, aesthetic sensitivity need not be a unitary construct: People might be sensitive to some features but not others (Clark et al., 1913). Fourth, unlike Götz et al.'s (1979) or Parker's (1978) notion, aesthetic sensitivity need not be immutable: People's aesthetic sensitivity might be influenced by context, experience, expertise, and maybe even fatigue (Robbins et al., 1915).

Corradi et al. (2020) mapped out the variation inherent to their conception of aesthetic sensitivity defined in the previous paragraphs regarding balance, contour–curvature, symmetry, and complexity in the visual modality. Although, in general, balance was preferred to unbalance, curvature to angularity, symmetry to asymmetry, and complexity to simplicity, people differed considerably from each other in the extent to which they were aesthetically sensitive to each of those attributes. Whereas some people were insensitive to complexity, others consistently preferred complex designs, and others consistently preferred simple ones. The same was true for symmetry, balance, and contour–curvature. Additionally, Corradi et al. (2020) did not find strong evidence of relations among aesthetic sensitivities to these four attributes. This supports the notion of aesthetic sensitivity as a multidimensional construct: Someone's liking can be strongly determined by one attribute but not another.

These findings raise the question of whether people also differ to such a great extent in their aesthetic sensitivity to attributes in other sensory modalities. As noted by Clemente et al. (2020), the aesthetic appreciation or valuation of music depends on many factors, such as cultural background, familiarity, experience, perceived complexity, or predictability (Brattico & Pearce, 2013; Koelsch et al., 2018; Pereira et al., 2011; Van den Bosch et al., 2013). People are not passive responders to music. Musical experiences are actively constructed by each individual relying on perceptual, cognitive, and affective processes that depend on knowledge, past experience, personal and cultural meaning, motivations, goals, and other individual and contextual circumstances.

Thus, the appreciation of music is a complex phenomenon that can, and must, be studied from a variety of perspectives using a variety of approaches. The question we ask here is whether people construct different preferences because, among many other things, they take into account different musical aspects to different extents: Might two people differ in their preference for a musical piece because, in constructing their preferences, one takes complexity into account and the other does not? If so, do they do so consistently? There is evidence suggesting that this is the case. For example, dissonance contributes to the perceived complexity of Western music, but people differ considerably in the extent to which they dislike dissonance (e.g., McDermott et al., 2010; Plomp & Levelt, 1965). There are also remarkable differences across cultures in the extent to which dissonance is disliked (e.g., McDermott et al., 2016; McPherson et al., 2019). The musical context in which the stimuli are presented and the degree of Western tonal-functional enculturation seem to be key factors explaining variations in individual preference for consonance.

The present study had three main goals: First, we wished to apply Corradi et al.'s (2020) conception of aesthetic sensitivity to music. Specifically, we wished to characterize musical aesthetic sensitivity to four attributes that figure prominently in the literature on visual aesthetics: balance, contour, symmetry, and complexity. There is some evidence for common effects of complexity on the appreciation of visual and musical materials (e.g., Marin et al., 2016; Marin & Leder, 2013), and there is also some evidence for individual differences in aesthetic sensitivity to complexity (Güçlütürk et al., 2016; Güçlütürk & van Lier, 2019; Marin & Leder, 2018). In the present study, we aim to corroborate and generalize this work to balance, symmetry, and contour. Thus, we assessed aesthetic sensitivity to these four attributes through sets of stimulus features that define them. Based on Corradi et al.'s (2019, 2020) results, we hypothesized (a) significant effects of these attributes on liking and (b) substantial variation in the extent to which these attributes influence individuals' aesthetic valuation. Second, we examined the temporal stability of musical aesthetic sensitivities. Considering Corradi et al.'s (2020) findings in the visual domain, we hypothesized (c) that people's aesthetic sensitivity to musical balance, contour, symmetry, and complexity are also stable in time. Third, we analyzed the relations among aesthetic sensitivities to probe whether the individual magnitude and direction of sensitivity are common across attributes and if such personal sensitivities converge into sensitivity profiles. Corradi et al. (2020) found no strong relations among visual aesthetic sensitivities to balance, contour, symmetry, and complexity. However, the extant literature does not allow us to form a particular hypothesis regarding the clustering of participants based on the pattern of their aesthetic sensitivities. Therefore, this analysis was conducted on an exploratory basis.

Method

Participants

Forty-eight self-reported nonmusicians (39 women and nine men) aged 18–44 years (*M* = 21.560, *SD* = 5.845) and recruited at the university campus took part in the study. No participant had received musical education at a university level, and the mean duration of their formal education in music was 5.354 years (*SD* = 4.111). Before participation, all gave informed consent and reported normal or corrected-to-normal vision and hearing and no cognitive impairments. They were unaware of the study's purpose and treated under the local ethical guidelines and the Declaration of Helsinki. The study received approval from the Committee for Ethics in Research of the Balearic Islands (IB 3573/17 PI).

Materials

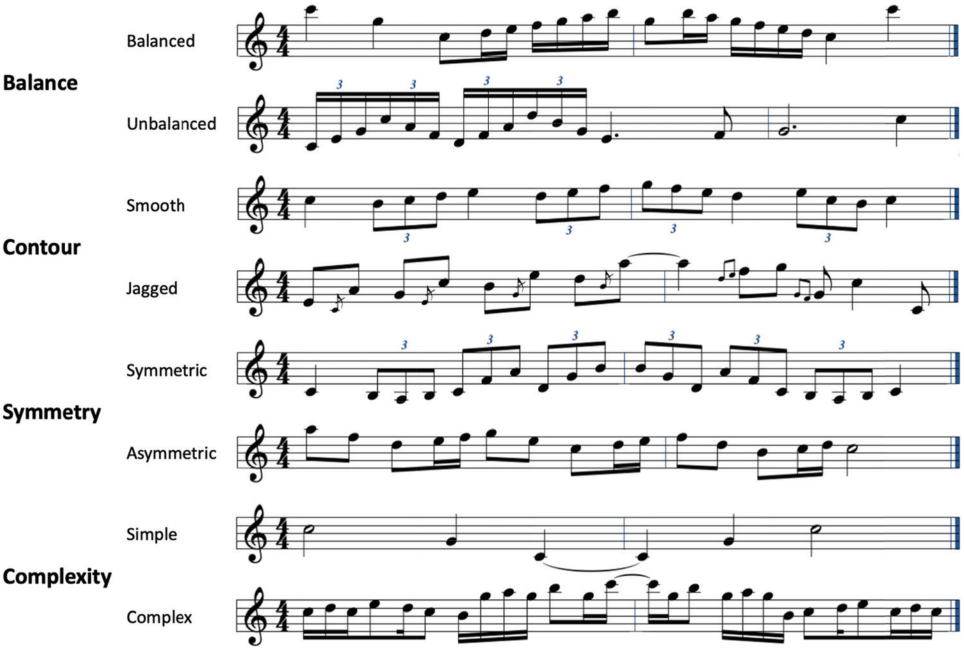
Clemente et al.'s (2020) MUST set of stimuli consists of 4-s monophonic piano-like motifs in C-major that systematically vary in musical balance, contour, symmetry, and complexity. They were composed expressly for empirical studies and designed to combine experimental control and musical appeal. The design of the MUST stimuli is schematically depicted in Table A1 (see Appendix A). In the present study, we used the MUST abridged stimulus set, which includes 24 motifs (plus four examples) for each of the four attributes. The abridged Balance subset includes 12 *balanced* and 12 *unbalanced* motifs; the abridged Contour subset includes 12 *smooth* and 12 *jagged* motifs; the abridged Symmetry subset includes 12 *symmetric* and 12 *asymmetric* motifs; the abridged Complexity subset includes 12 *simple* and 12 *complex* motifs (see Figure 1). The stimuli were presented in WAV format using Open Sesame (Mathôt et al., 2012).

The MUST (Clemente et al., 2020) also includes composite computational measures specific for the structural features characteristic of each subset: Balance and symmetry were defined by single composite measures of balance (BC1) and symmetry (SC1), respectively. Two components quantified the structural parameters of contour: one for melodic (pitch-related) contour (CC1) and the other for rhythmic contour (CC2). Likewise, two components quantified complexity: a measure of melodic complexity KC1 (event density and pitch-related entropy) and a measure of rhythmic complexity KC2 (duration entropy). Higher values correspond to greater unbalance, jaggedness, asymmetry, and complexity, respectively. We include a summary of the computational measures in Table A2 (see Appendix A). The computational assessment showed that stimuli in each of the attributes' poles differ substantially in the corresponding defining features, and the behavioral assessment showed that people rate them as belonging to two opposite extremes (Clemente et al., 2020). The MUST set and computational measures are available at https://osf.io/bfxz7/.

Procedure

Participants undertook the experimental tasks in the laboratory. They were first welcomed and briefed about the entire procedure. Each participant was then asked to enter one of the individual sound-attenuated testing cabins, all of which have the same computers, software, adequate light conditions, and headphone sets. After providing verbal and onscreen instructions, each subset was presented in a separate block, which consisted of four practice trials (two illustrative of each pole) and the 24 task stimuli. All stimuli were presented through headphones. The order of the blocks was counterbalanced between participants, and the order of presentation within each block was randomized for each participant. During the practice trials, participants adjusted their headsets to personal comfort levels, which remained unmodified for the whole

Figure 1

Sample Scores of Auditory Stimuli in Each Subset

Note. All to be played in ♩ = 120 (i.e., quarter note at 120 bpm). See the online article for the color version of this figure.

experiment. After the experimenter had made sure participants understood the task and all doubts had been resolved, participants listened to and rated the task stimuli.

Participants rated how much they liked each of the 24 musical motifs in each subset twice: in the test and retest experimental sessions two weeks apart. They rated each motif using a keyboard on a 5-point Likert scale anchored by *not at all* (1) to *very much* (5). They were explicitly requested to base their responses on the subjective internal feelings of pleasure, interest, enjoyment, or desirability evoked, inspired, or provoked by the music. They were allowed to take breaks between blocks and to replay a stimulus before rating it if they so desired. A brief questionnaire (included as Appendix B) followed the fourth block in the test phase and asked about demographics (i.e., age, sex, and education) and formal musical education (i.e., highest degree attained, onset, and duration). Finally, participants were debriefed and thanked for their time and participation. Test and retest sessions lasted about 30 and 15 min, respectively.

Data Analysis

All analyses were performed within the R environment for statistical computing, v. 3.6.0 (R Core Team, 2018). In the course of conducting the analyses, we found that two pairs of stimuli belonging to the Symmetry and Complexity abridged subsets were duplicated; that is to say, the same stimulus had erroneously been included in the symmetry and complexity subsets: S4 = K8 and S5 = K9. We, therefore, decided to exclude them from the analyses, leaving us with 12 *balanced* – 12 *unbalanced*, 12 *smooth* – 12 *jagged*, 10 *symmetric* – 12 *asymmetric*, and 10 *simple* – 12 *complex.*

Musical Aesthetic Sensitivity

We performed four linear mixed-effects analyses (Hox et al., 2010; Snijders & Bosker, 2012) to assess the effect of the main predictors on participants' liking judgments in the test phase. This method accounts simultaneously for the between-subjects and within-subjects effects of the independent variables (Baayen et al., 2008) and models random error at all levels of analysis simultaneously, relying on maximum-likelihood procedures to estimate coefficients. Therefore, it provides the most accurate analysis of hierarchically structured data in which, as is the case here, responses to stimuli are dependent on, or nested within, individual participants (Nezlek, 2001). Linear mixed-effects models provide other additional advantages, such as meaningful estimates of subject- and group-level variance components, unbiased handling of outliers, and ability to handle incomplete and unbalanced data and to accommodate continuous and categorical predictors (Judd et al., 2012). Importantly, they allow deriving conclusions that generalize to other participants besides those providing the data (Judd et al., 2017; Nezlek, 2001). They are especially well suited to the purposes of the current study because they provide estimates for both group-level effects, which can be compared with those of previous studies, and participant-level effects, which constitute our measure of individual aesthetic sensitivity (as in Corradi et al., 2020).

The models were designed to reflect the effect of the features varied on participants' liking. Thus, we modeled participants' responses as a function of Clemente et al.'s (2020) MUST composite measures: liking for musical balance predicted by BC1; liking for musical contour with predictors CC1, CC2, and their interaction (CC1 × CC2); liking for musical symmetry predicted by SC1; and liking for musical complexity with predictors KC1, KC2, and their interaction (KC1 × KC2). All predictors were mean-centered. The models included the respective composite measures as fixed effects. The models of liking for contour and complexity also included the interaction between melodic (CC1) and rhythmic (CC2) contour, and between melodic (KC1) and rhythmic (KC2) complexity, respectively, as fixed effects. The four resulting models also included the slope for each feature and their interactions (when appropriate) as random effects within participants, and random intercepts within stimuli, following Barr et al.'s (2013) recommendation to model the maximal random-effects structure justified by the experimental design. To assess the effects of familiarity, we also ran the models including repeated listening as a predictor.

Although the mixed-effects models produce group estimates, the main goal of this study was to understand individual differences in the extent to which these four attributes influence people's liking. In linear mixed-effects models, this corresponds to the individual slopes. Thus, we defined participants' aesthetic sensitivity to each composite measure as the individual slope estimated from the models' random-effect structure. Therefore, after running each model, we extracted each participant's slopes. We used these values to describe individual aesthetic sensitivities to musical balance, contour, symmetry, and complexity, and to explore relations among them. We investigated the distribution of slopes for each predictor and used Shapiro–Wilk tests to assess their normality.

We performed these analyses using the lmer() function of the *lme4* package (Bates et al., 2015) fitted with REML estimation. The *lmerTest* package (Kuznetsova et al., 2012) was used to estimate the *p* values for the *t* tests based on the Satterthwaite approximation for degrees of freedom, which has been shown to produce acceptable type-I error rates (Luke, 2017).

Test–Retest Differences

The estimation of participants' aesthetic sensitivity to the four attributes was done exactly as described above for the test and retest data. Thus, for each participant, we had two measures of aesthetic sensitivity for each of the four attributes taken two weeks apart. We were, therefore, able to determine the test–retest reliability of aesthetic sensitivity to each feature. The analysis was based on Bland and Altman's (1986) method and the smallest real difference (SRD; Vaz et al., 2013). Like other methods to estimate test–retest reliability, Bland and Altman's (2003) method quantifies variation between repeated measurements. The advantages of their graphical method are that it is robust to the data variability and can detect systematic biases in the differences between two repeated measurements. This method establishes statistical boundaries for detecting a test–retest difference, namely the threshold for change or minimal detectable true change (Vaz et al., 2013). The limits of agreement are set at 1.96 times the standard deviation above and below this difference, defining the smallest real difference (SRD; Vaz et al., 2013). When this interval contains the value 0, the test–retest difference can be attributed to error (Beckerman et al., 2001). Otherwise, it can be attributed to some form of systematic bias. Bland and Altman's (1986) graphs plot the test–retest differences against the average and, thus, allow identifying cases where changes indicate a shift in aesthetic sensitivity. We used the R package *BlandAltmanLeh* (Lehnert, 2015).

Relations Between Aesthetic Sensitivities

To investigate how aesthetic sensitivities were related within individuals, we first inspected the correlations between individual slopes. Second, we wished to know whether combinations of sensitivities characterized the liking distributions, and if such combinations were finite and followed any pattern, so we performed a cluster analysis.

Cluster analysis or clustering is a common procedure in exploratory data mining and a standard for statistical data analysis. It is used in many fields, including machine learning, pattern recognition, image analysis, or music information retrieval. Clustering consists in grouping a set of objects in such a way that objects in the same group or cluster are more similar in a particular aspect to each other than to those in other groups or clusters. Therefore, it is an iterative process of knowledge discovery or interactive multiobjective optimization. Cluster analysis can be achieved by various algorithms that differ significantly in their definition of clusters and how to find them efficiently. The appropriate clustering algorithm and parameter settings (e.g., distance function to use, density threshold, number of expected clusters) depend on the particular data set and intended use of the results. The most prominent examples of clustering algorithms include hierarchical clustering, centroid-based clustering (such as the popular *k*-means, in which the number of clusters is predetermined to *k*), distribution-based clustering (e.g., Gaussian mixture models), density-based clustering, or grid-based clustering.

We applied Gaussian finite-mixture models fitted via the expectation-maximization (EM) algorithm for model-based clustering, classification, and density estimation, including Bayesian regularization, dimension reduction for visualization, and resampling-based inference. We chose it over partitioning methods because the data points were not necessarily assumed to belong to only one cluster, and this method allows the number of clusters to emerge from the data (Melnykov & Maitra, 2010). This analysis was applied to both test and retest data to ascertain whether the clustering structure held over time. We used the R package *mclust* (Scrucca et al., 2016).

Impact of Demographics

As a matter of routine, we examined the correlations between aesthetic sensitivities and demographic variables. To test whether, and to what extent, these traits predicted the clustering, we also performed a multiple linear regression analysis. As we did not have any specific hypothesis nor expect these variables would exert any effect on liking or on the configuration of the clustering, these analyses were deemed exploratory.

Results

Musical Aesthetic Sensitivity

We modeled liking judgments for stimuli in each subset as a function of the corresponding parameters of variation, as assessed by the MUST composite measures. This made a total of four linear mixed-effects models in the test phase and four more in the retest phase. In this section, we report the results of the analyses corresponding to the test phase. For each feature, we first report the group-level trends and then descriptive statistics that characterize the distributions of individual aesthetic sensitivities.

Balance

The analysis of the balance model showed that, overall, participants found the stimuli appealing (intercept: $\beta = 3.240$, $t[42.827] = 28.537$, $p < .001$) and that they liked the balanced motifs more than the unbalanced ones: $\beta = -.276$, $t(23.845) = -3.057$, $p = .005$ (Figure 2A). The individual slopes of liking for balance ranged from $-.482$ to $-.126$, indicating different degrees in the extent to which participants liked the balanced motifs, with $M = -.276$, $SD = .074$. The Shapiro–Wilk normality test showed that the slopes of liking for balance were normally distributed ($W = .985$, $p = .774$; Figure 3A).

Contour

The analysis of the contour model revealed that, overall, liking judgments were positive (intercept: $\beta = 3.450$, $t[52.084] = 34.649$, $p < .001$) and predicted by the two composite contour measures separately but not by their interaction: $\beta = -.023$, $t(23.825) = -.409$, $p = .686$. In general, participants liked more melodic jaggedness (CC1; $\beta = .224$, $t[36.306] = 2.698$, $p = .011$; Figure 2B) and rhythmic smoothness (CC2; $\beta = -.185$, $t[21.050] = -2.173$, $p = .041$; Figure 2C). The individual slopes of liking for CC1 ranged from $-.392$, indicating a greater liking for melodic smoothness, to .829, indicating a greater liking for melodic jaggedness, with $M = .224$, $SD = .283$. The individual slopes of liking for CC2 ranged from $-.365$ to $-.059$, indicating a greater liking for rhythmic smoothness, with $M = -.185$, $SD = .077$. The Shapiro–Wilk normality test indicated that the individual sensitivities to contour were normally distributed for CC1 ($W = .957$, $p = .079$; Figure 3B) and CC2 ($W = .959$, $p = .092$; Figure 3C).

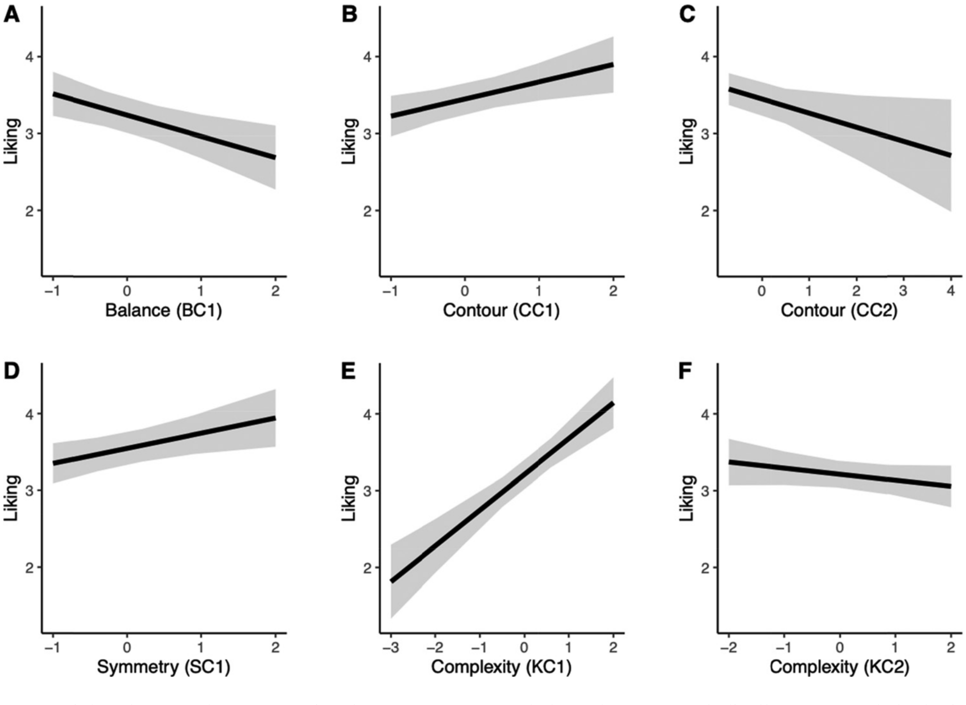
Symmetry

The analysis of the symmetry model showed that, overall, participants rated the stimuli positively (intercept: $\beta = 3.549$, $t[44.777] = 33.115$, $p < .001$) and liked the asymmetric more than the symmetric motifs: $\beta = .198$, $t(20.316) = 2.506$, $p = .021$ (Figure 2D). The individual slopes of liking for symmetry ranged from .160 to .233, indicating a greater liking for asymmetric motifs, with $M = .198$, $SD = .018$. The liking slopes for symmetry were normally distributed according to the Shapiro–Wilk normality test ($W = .967$, $p = .187$; Figure 3D).

Complexity

The analysis of the model of liking for complexity unveiled that, overall, participants' liking was positive (intercept: $\beta = 3.211$, $t[51.427] = 36.436$, $p < .001$) and increased with melodic complexity (KC1), the only significant effect: $\beta = .466$, $t(45.415) = 6.236$, $p < .001$ (Figure 2E). The effect of rhythmic complexity (KC2) was not significant: $\beta = -.080$, $t(21.427) = -1.376$, $p = .183$ (Figure 2F). The

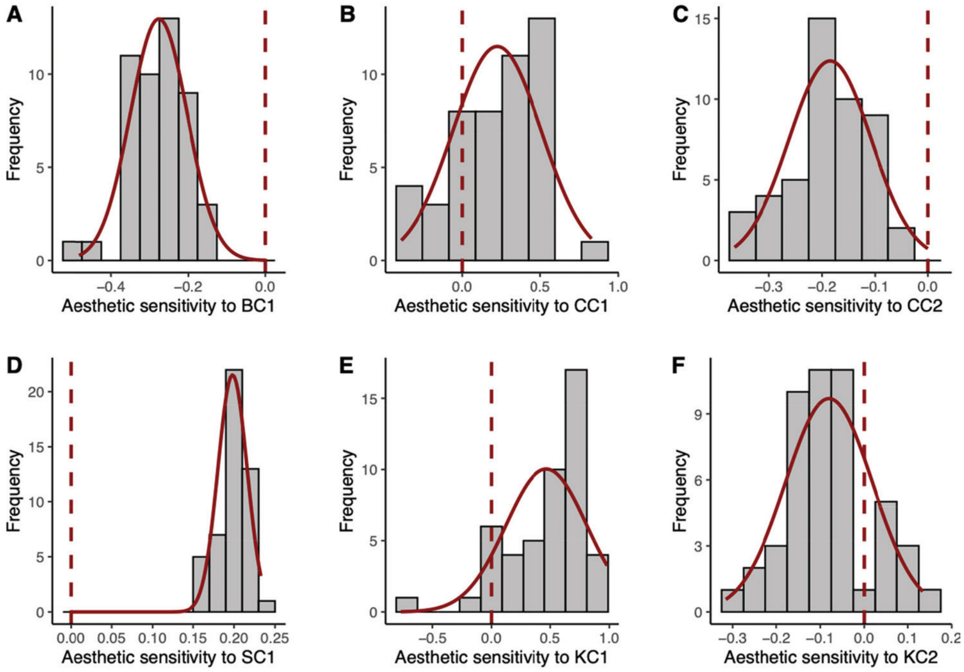
Figure 2
Main Effects of Balance (A), Contour (B and C), Symmetry (D), and Complexity (E and F) on Participants' Liking



Note. High values on the computational measures mean unbalanced (BC1), melodically (CC1) and rhythmically (CC2) jagged, asymmetric (SC1), and melodically (KC1) and rhythmically (KC2) complex, respectively. Gray ribbons correspond to 95% CI.

Figure 3

Individual Aesthetic Sensitivity to Musical Attributes: Histograms of Individual Slopes of Liking for Balance (A), Contour (B and C), Symmetry (D), and Complexity (E and F)



Note. Vertical dashed lines correspond to a slope of 0, meaning absolute indifference or insensitivity toward each attribute concerning liking judgments. Positive slopes indicate a higher liking for unbalanced (BC1), melodically (CC1) and rhythmically (CC2) jagged, asymmetric (SC1), and melodically (KC1) and rhythmically (KC2) complex motifs. Negative slopes indicate a higher liking for balanced (BC1), melodically (CC1) and rhythmically (CC2) smooth, symmetric (SC1), and melodically (KC1) and rhythmically (KC2) simple motifs. Normal curves are overlaid in dark red (dark gray). Only the individual slopes of liking for symmetry (SC1) and melodic complexity (KC1) were not normally distributed. See the online article for the color version of this figure.

effect of the interaction between KC1 and KC2 was also not significant: β = −.022, *t*(19.877) = −.494, *p* = .627. The estimated slopes for KC1 ranged from −.771, indicating a greater liking for melodically simple motifs, to .981, indicating a greater liking for melodically complex motifs, with *M* = .466, *SD* = .343. According to the Shapiro–Wilk normality test, the slopes of liking for melodic complexity (KC1) were not normally distributed ($W = .905$, $p < .001$), with skew = −1.150, and kurtosis = 1.615 (Figure 3E). The slopes of liking for KC2 ranged from −.315, indicating a greater liking for rhythmically simple motifs, to .134, indicating a greater liking for rhythmically complex motifs, with *M* = −.080, *SD* = .099. The slopes of liking for KC2 were normally distributed according to the Shapiro–Wilk normality test ($W = .977$, $p = .457$; Figure 3F).

Test–Retest Differences

We analyzed the retest data following the same procedure as reported for the test phase. Then, we examined test–retest changes in individual participants' aesthetic sensitivity to each feature applying Bland–Altman's graphic method and the smallest real difference (SRD).

Table 1 shows the results of the analysis based on the smallest real difference (SRD), and Figure 4 displays the corresponding Bland–Altman graphs. These analyses revealed that whereas the test–retest differences in the assessment of aesthetic sensitivity to melodic contour (CC1) and melodic (KC1) and rhythmic (KC2) complexity can be attributed to random error, this is not the case for aesthetic sensitivity to musical balance (BC1), symmetry (SC1), and rhythmic contour (CC2), where there is a systematic bias in the differences. Participants were more sensitive to rhythmic contour (CC2) and symmetry (SC1) in the retest phase. In the case of balance (BC1), participants were less sensitive in the retest phase.

The Bland-Altman analyses showed that these systematic biases owed to changes in the aesthetic sensitivity of few participants. In total, only 17 of 288 individual sensitivities to the four aesthetic attributes (6%) exceeded the SRD. In the case of musical balance (BC1), three participants (6%) showed lower sensitivity in the retest. Regarding rhythmic contour (CC2), five participants exceeded the SRD: four (8%) were more sensitive in the retest, and one (2%) in the test phase. As for symmetry (SC1), two participants (4%) were more and one was less (2%) sensitive in the retest phase. One participant exceeded the SRD for three of the

Table 1

Test–Retest Differences: Bland–Altman Analysis

Feature	Mean retest–test difference	95% CI Lower	95% CI Upper	Smallest real difference (SRD)
BC1	−0.045	−0.073	−0.017	0.189
CC1	−0.018	−0.082	0.045	0.426
CC2	0.044	0.019	0.069	0.167
SC1	0.026	0.006	0.046	0.135
KC1	−0.030	−0.104	0.043	0.496
KC2	−0.009	−0.073	0.017	0.190

Note. Mean difference and smallest real difference: measures of test–retest reliability for aesthetic sensitivity to musical balance (BC1), melodic (CC1), and rhythmic (CC2) contour, musical symmetry (SC1), and melodic (KC1) and rhythmic (KC2) complexity.

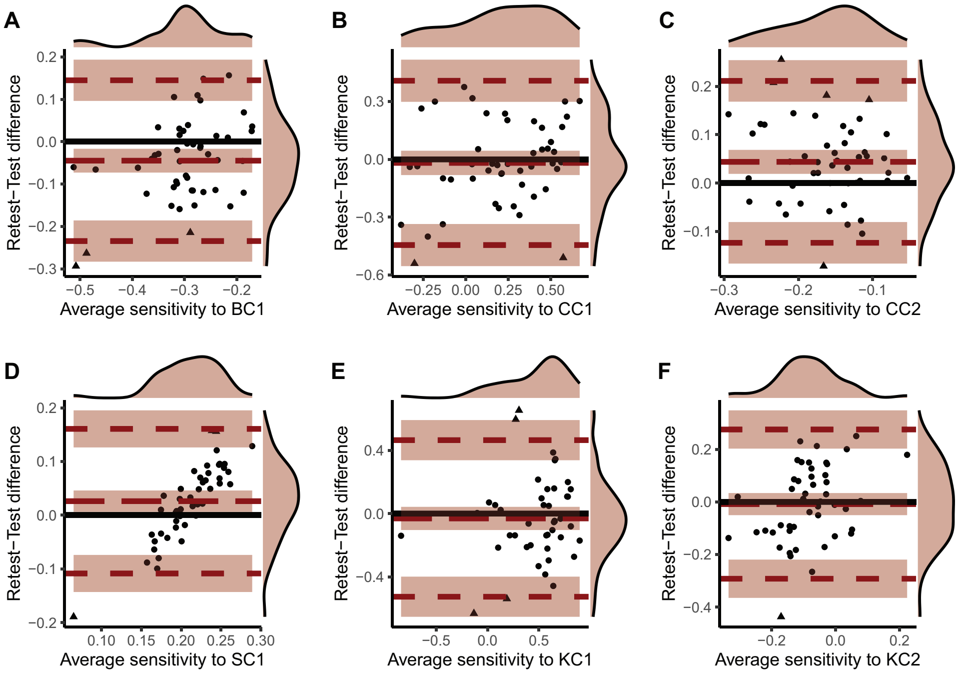
features, and another participant, for two of them. No participant exceeded the SRD for more than three features.

Relations Between Aesthetic Sensitivities

As a first approach to the relationships between sensitivities within participants and given that not all distributions of aesthetic sensitivities were normal according to the Shapiro–Wilk tests, we calculated Spearman correlations between aesthetic sensitivities in the test phase (see Table 2). These indicate that people who like melodically jagged contours also tend to prefer rhythmically jagged, less balanced, and more asymmetric and complex motifs, and people who like more melodically complex music also tend to like more asymmetric and jagged motifs. Aesthetic sensitivities to melodic and rhythmic contour show particularly strong correlations, suggesting that people who like more jagged contours do so for both pitch-related and rhythmic aspects of musical contour. Also, aesthetic sensitivity to melodic contour is moderately

Figure 4

Bland–Altman Graphs for the Test–Retest Reliability of Aesthetic Sensitivity to Balance (BC1; A), Melodic Contour (CC1; B) Rhythmic Contour (CC2; C), Symmetry (SC1; D), Melodic Complexity (KC1; E) and Rhythmic Complexity (KC2; F)



Note. Horizontal continuous black lines represent no test–retest change. Horizontal long-dashed red lines indicate the mean test–retest difference. Horizontal dashed lines mark the lower and higher limits of agreement. Horizontal ribbons comprise 95% CI. Circles correspond to participants whose test–retest difference is smaller than the smallest real difference (SRD). Triangles correspond to participants whose test–retest difference is larger than the SRD. See the online article for the color version of this figure.

correlated with that for balance, suggesting that people who like more jagged melodies also tend to like less balanced ones. Interestingly, preference for either form of musical jaggedness shows moderate to strong correlations with melodic complexity, whereas aesthetic sensitivity to these three structural properties present weaker (moderate) correlations with aesthetic sensitivity to symmetry.

In addition to pairwise correlations, clustering provides a comprehensive picture of the multiple relationships of individual aesthetic sensitivities within and between individuals. In the test phase, the Gaussian finite-mixture model fitted by the EM algorithm revealed the existence of two clusters (log-likelihood [48] = −361.341, BIC = −780.750, ICL = −785.724). Cluster 1T (for *test*) included 21 participants who, overall, liked more balanced, smooth, symmetric, and simple motifs. Cluster 2T included 27 individuals who generally liked more unbalanced, jagged, asymmetric, and complex motifs (see Table 3).

In the retest phase, the Gaussian finite-mixture model fitted by the EM algorithm revealed the existence of three clusters (log-likelihood [48] = −355.645, BIC = −800.328, ICL = −807.542). Cluster 1R (for *retest*) was made up of 16 participants who, overall, liked more balanced, smooth, asymmetric, and melodically simple motifs. Cluster 2R included 19 individuals who generally liked more unbalanced, jagged, symmetric, melodically complex, and rhythmically simple motifs. Cluster 3R was made up of 13 participants who tended to like more balanced, jagged, asymmetric, and complex motifs (see Table 4). Cluster 1R corresponds for the most part to Cluster 1T, whereas Clusters 2R and 3R suggest a more detailed picture for the trends characterizing Cluster 2T. Most participants (14) belonging to Cluster 1T in the test phase integrated Cluster 1R, while five fell into Cluster 2R and two into Cluster 3R at retest. Only two participants in Cluster 2T shifted to Cluster 1R, while the rest were distributed into Clusters 2R and 3R.

Impact of Demographics

We examined the extent to which individual aesthetic sensitivities and cluster allocation were influenced by demographic variables. Most participants in this study had only studied music at primary and secondary school, and the mean duration of their formal education in music was five years (see Participants). We found no significant associations between liking judgments and age, sex, highest general academic degree attained, highest music degree obtained, nor onset or duration of formal education in music (see Table 5). Likewise, the multiple linear regression analysis of aesthetic sensitivities revealed no significant influence of the demographic variables on whether participants were allocated to one cluster or another (see Table 6).

Table 2

Spearman Correlations Among Aesthetic Sensitivities in the Test Phase

Feature	BC1	CC1	CC2	SC1	KC1
CC1	0.553†				
CC2	0.442**	0.828†			
SC1	0.157	0.382**	0.299*		
KC1	0.232	0.613†	0.641†	0.333*	
KC2	0.175	0.033	0.086	−0.057	−0.181

Note. Pairwise Spearman correlations among aesthetic sensitivities to musical balance (BC1), melodic contour (CC1), rhythmic contour (CC2), musical symmetry (SC1), melodic complexity (KC1), and rhythmic complexity (KC2).

$^{\dagger}p < .0001$. $^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

Table 3

Model-Based Clustering of Individual Slopes of Liking Ratings in the Test Phase

Cluster	BC1	CC1	CC2	SC1	KC1	KC2
Cluster 1T (21)	−0.631	−0.858	−0.770	−0.460	−0.618	−0.096
Cluster 2T (27)	0.516	0.702	0.630	0.376	0.505	0.079

Note. Estimates of aesthetic sensitivity for each cluster. Positive values indicate a greater liking for unbalanced (BC1), melodically (CC1) and rhythmically (CC2) jagged, asymmetric (SC1), and melodically (KC1) and rhythmically (KC2) complex motifs. Negative values indicate a greater liking for balanced (BC1), melodically (CC1) and rhythmically (CC2) smooth, symmetric (SC1), and melodically (KC1) and rhythmically (KC2) simple motifs.

Repeated Listening

Overall, only 4.2% of responses involved repeated listening (i.e., repeating the stimulus before rating it): 5.2% in the Balance subset, 3.8% in the Contour subset, 4.3% in the Symmetry subset, and 3.7% in the Complexity subset. To examine the impact of familiarity on liking, we reran the linear mixed-effect models for the test data including repeated listening as a predictor. We found no significant effects of stimulus repetition on liking ratings (all ps > .050). For the contour subset, the model was unusable, as it failed to converge with one negative eigenvalue (−.17): $\beta = -.348$, $t(51.137) = -2.009$, $p = .050$.

Discussion

Empirical aesthetics has traditionally focused on simple and general laws governing the relation between sensory features and appreciation. In this line, research shows that people generally prefer symmetry to asymmetry (Gartus & Leder, 2013; Jacobsen & Höfel, 2001; Pecchinenda et al., 2014), complexity to simplicity (Machado et al., 2015; Nadal et al., 2010), and curved to angular contours (Bertamini et al., 2016; Corradi et al., 2020; Gómez-Puerto et al., 2018; Palumbo et al., 2015).

Table 4

Model-Based Clustering of Individual Slopes of Liking Ratings in the Retest Phase

Cluster	BC1	CC1	CC2	SC1	KC1	KC2
Cluster 1R (16)	−0.612	−0.950	−0.864	0.173	−0.822	0.081
Cluster 2R (19)	0.621	0.362	0.182	−0.527	0.272	−0.392
Cluster 3R (13)	−0.116	0.768	0.928	0.586	0.729	0.502

Note. Estimates of aesthetic sensitivity for each cluster. Positive values indicate a higher liking for unbalanced (BC1), melodically (CC1) and rhythmically (CC2) jagged, asymmetric (SC1), and melodically (KC1) and rhythmically (KC2) complex motifs. Negative values indicate a higher liking for balanced (BC1), melodically (CC1) and rhythmically (CC2) smooth, symmetric (SC1), and melodically (KC1) and rhythmically (KC2) simple motifs.

Table 5

Spearman Correlations Among Numeric Demographic Variables and Aesthetic Sensitivities in the Test Phase

Variable	BC1	CC1	CC2	SC1	KC1	KC2
Age	−0.067	0.150	0.124	0.163	0.084	0.153
Education	0.154	−0.089	−0.099	−0.027	−0.190	0.234
Musical education	−0.036	−0.028	0.081	−0.069	−0.012	−0.036
Musical studies duration	−0.068	0.033	0.062	0.028	−0.012	−0.079
Musical studies onset	0.148	0.194	0.134	0.081	0.234	−0.219

Note. Pairwise Spearman correlations among demographic variables and aesthetic sensitivities to musical balance (BC1), melodic contour (CC1) rhythmic contour (CC2), musical symmetry (SC1), melodic complexity (KC1) and rhythmic complexity (KC2).

However, general trends do not imply uniformity. Research shows, in fact, that people differ remarkably in the way they respond to symmetry (Leder et al., 2019), complexity (Chmiel & Schubert, 2018), regularity (Friedenberg, 2018), and curved contours (Corradi et al., 2019). Such differences illustrate how inadequate the notion of simple and general laws linking sensory features and hedonic valuation is (Skov & Nadal, 2020a). Aesthetic appreciation is shaped by context, cultural and personal meaning, familiarity and past experience, expertise, anticipation and expectations, as well as current mood and emotions, and bodily states (Skov & Nadal, 2020b). Previous work has shown that it is also shaped by aesthetic sensitivity: people differ in their hedonic valuation of visual objects because they consistently differ in the extent to which they rely on certain attributes (Corradi et al., 2019, 2020).

The overarching goal of the study presented here was to extend our research on aesthetic sensitivity to music, asking whether people differ in their preference for musical motifs because they take into account different attributes to different degrees. To facilitate comparison with studies in other modalities such as Corradi and colleagues' (2020), we used a set of musical motifs that enable the experimental control and computational quantification of balance, contour, symmetry, and complexity in the auditory domain while preserving musical appeal (Clemente et al., 2020). We had three specific goals: first, to characterize musical aesthetic sensitivity to balance, contour, symmetry, and complexity; second, to determine whether people's aesthetic sensitivity to these attributes is stable in time; and third, to ascertain whether there are common patterns of aesthetic sensitivities that lead people to fall into defined profiles.

Table 6

Multiple Linear Regressions for the Impact of Demographics on Cluster Allocation

Variable	Estimate	*SE*	*t* value	Pr(>|*t*|)
(Intercept)	1.001	0.420	2.385	0.022*
Age	−0.021	0.014	−1.489	0.144
Gender (woman)	−0.078	0.192	−0.408	0.685
Education	0.052	0.120	0.436	0.665
Musical education	−0.101	0.194	−0.521	0.605
Musical studies duration	−0.004	0.017	−0.227	0.821
Musical education	−0.019	0.021	−0.886	0.381

Note. Impact of demographic variables on individual loadings into clusters according to musical aesthetic sensitivities.
$^{\dagger}p < .0001$. $^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

The intercepts for all models were above the midscore (i.e., βs > 3.000), which indicates that participants found the stimuli generally appealing. The results also revealed general liking trends: overall, balanced, melodically jagged, rhythmically smooth, asymmetric, and melodically complex motifs were liked more than unbalanced, smooth, symmetric, and simple. Melodic complexity (KC1) was a much stronger predictor of perceived musical complexity than rhythmic complexity (KC2) in Clemente et al. (2020). Thus, it is not surprising that the contribution to liking judgments of melodic complexity was also greater than that of its rhythmic counterpart, which did not even reach statistical significance in the present study. Considering our results with music together with those of Corradi et al. (2020) with visual designs, liking for both music and images seems to increase with balance and complexity, whereas the trends for contour and symmetry differ between sensory domains. Further research addressing aesthetic sensitivity across modalities within participants will elucidate the implications of these similarities and differences.

Beyond these general trends, our results confirmed the hypothesized considerable differences among participants in the extent to which musical features influenced liking. These findings are in line with those of Güçlütürk et al. (2016), Güçlütürk and van Lier (2019), and Marin and Leder (2018), highlighting the importance of understanding individual differences that coexist with general trends. The estimated individual aesthetic sensitivities for musical balance (−.482, −.126), symmetry (.160, .233), and rhythmic contour (−.365, −.059) varied within one pole, pointing to a consistent tendency across participants. In contrast, liking for melodic contour (−.392, .829) and for melodic (.771, .981) and rhythmic (−.315, .134) complexity varied widely, including people either insensitive or very sensitive to these features, strongly and consistently preferring either extreme. These outcomes concur with prior findings in the visual domain (Corradi et al., 2019, 2020): also in music, a substantial proportion of the variance is accounted for by differences between individuals in the influence that such features exert upon aesthetic judgments. Hence, our study adds to mounting evidence for caution when interpreting general trends in liking and preference (Corradi et al., 2019; Güçlütürk et al., 2016; Güçlütürk & van Lier, 2019).

The results also confirmed our hypothesis that aesthetic sensitivity to musical attributes is stable in time: according to the Bland–Altman analysis, most participants were consistent in their judgments at test and retest. The average differences in liking for balance, rhythmic contour, and symmetry were driven by a small number of participants more sensitive to rhythmic contour and symmetry, and less to balance at retest. These outcomes are comparable to those of Corradi et al. (2020) in the visual domain: They found that most participants were consistent between test and retest, and that systematic differences in aesthetic sensitivities to visual symmetry and complexity were attributed to very few participants. In both Corradi et al. (2020) and our study, participants showed higher sensitivity to symmetry in the retest phase, suggesting either that sensitivity to this attribute may be especially susceptible to learning or that it is just unstable in both domains. However, the test–retest change observed for complexity differed slightly between domains: whereas sensitivity to visual complexity decreased at retest, aesthetic sensitivities to melodic and rhythmic complexity were stable.

We allowed the participants to repeat the motifs because the dimensions along which the stimuli varied might not have been graspable at first hearing, in the same way as the eyes move back and forth, reinspecting an image before assessing it. In hindsight, our precaution turned out to be unnecessary. The results suggest, first, that repetition seldom occurred, and second, that repeating the motif did not affect liking.

We found multiple significant correlations between different aesthetic sensitivities to structural features in our musical stimuli. We believe that the correlated sensitivities reflect underlying differences in participants' preference for informational predictability: Whereas some people seem to prefer higher uncertainty in different forms (such as larger number of notes or interval amplitude), others seem to prefer higher predictability in different forms (such as recurrent sound patterns, and smooth profiles).

Even if preliminary, the clustering revealed that although people differ in the extent to which musical features influence their liking, there is a certain regularity: People clustered together into two groups based on their aesthetic sensitivities to the musical features we examined. Individuals falling into the first aesthetic sensitivity profile tended to like more balanced, smooth, symmetric, and simple music. Conversely, the second aesthetic sensitivity profile covered the largest number of participants and was characterized by a tendency to like more unbalanced, jagged, asymmetric, and complex music. These results resemble those of Güçlütürk and van Lier (2019) on musical complexity. The averaged strengths of these preferences vary within and between clusters: The estimated preferences of the first cluster members are slightly more extreme than those of the second one. In other words, aesthetic sensitivity appears to be somewhat higher for the first than the second profile.

The basic structure of the clustering was retained in the retest, although in a more detailed manner: Clusters 1T and 1R correspond to the first aesthetic profile, and the second profile represented by Cluster 2T is distributed into Clusters 2R and 3R. Average ratings were more extreme in Cluster 3R, showing stronger preferences for jaggedness, asymmetry, and complexity, and even reverting the tendency for balance. In contrast, Cluster 2R showed a stronger preference for balance, milder preferences for jaggedness and melodic complexity than Cluster 2T, and preferences for symmetry and rhythmic simplicity failed into this cluster instead of Cluster 1R. The shifts in the estimates are attributable to few participants swapping clusters from test to retest. Overall, the influence of rhythmic contour was not significant and tended to indifference at test. However, it revealed more pronounced at retest despite the relative stability of individual sensitivities, again showing how averages may conceal individual differences. Replications with larger samples are required to confirm our findings.

Our results suggest a plausible cognitive mechanism underlying the appreciation of these properties, in line with research on predictability in music (Cheung et al., 2019; Gold et al., 2019), which could transcend sensory modalities and be related to other traits. Accordingly, participants clustered together as per their preference for high (profile 1) or low (profile 2) informational predictability. This is consistent with the simple correlations found among aesthetic sensitivities and manifested in balanced versus unbalanced event distributions, small versus larger and varied intervals and rhythmic figures, redundant versus different information, and simple versus complex motifs.

There are certain limitations to our results that are worth noting. First, our sample was musically homogeneous, mainly made up of university students with little formal musical training. Although this makes our results generalizable to nonmusicians, further research with more varied samples including musicians is required to elucidate the potential influence of musical expertise, experience, ability, and sophistication. Second, our stimuli were expressly designed for research purposes and therefore bounded in certain regards (e.g., duration, style, texture, timbre, loudness). Future research is required to determine whether our results would hold for more complex musical stimuli from a broader range of musical cultures (Jacoby et al., 2020). Finally, it remains to be determined how person-related factors, such as personality traits (e.g., openness to experience), socioeconomic status, and musical training and aptitude, influence aesthetic sensitivity and explain why people cluster into different aesthetic sensitivity profiles.

In conclusion, our results suggest that aesthetic experience is influenced by the balance, contour, symmetry, and complexity of music. Furthermore, the relationship between these attributes and aesthetic experience remains stable within individuals but varies between individuals. This supports a conception of aesthetic sensitivity that focuses on individual experience rather than a universal, objective aesthetic standard (Corradi et al., 2020). Individuals can show different aesthetic sensitivities to different features, leading to what we have referred to as an aesthetic sensitivity profile. The ultimate conclusion of these results questions the sense of general preference trends: if people differ so much when it comes to the way complexity (for instance) influences preference, does it make sense to say that "people generally prefer intermediate levels of complexity" when this general trend does not represent the enormous variability of ways people use (or not) complexity to determine their preference? We hope that these results contribute to creating a platform for a more sophisticated investigation of the nature of aesthetic experience in future research.

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Appendix A

The MUST Set and Toolbox (Adapted from Clemente et al., 2020)

Table A1
Summary of Parameters Used to Design the Musical Stimuli in Each Subset

		Feature	
Attribute	Parameter	*Balanced*	*Unbalanced*
Balance	Distribution of events	Regular	Irregular
	Climax position	Centered	Skewed
	Tension	Progressive	Unprepared
		Smooth	*Jagged*
Contour	Intervals	Only small (≤ 4ths)	Large (> 4ths) & small
	Durations	Progressive, small changes	Sudden, large changes
		Symmetric	*Asymmetric*
Symmetry	Vertical mirror structure	Yes	No
		Simpler	*More complex*
Complexity	Number of events	Few	Many
	Variety of events	Low	High
	Predictability	High	Low

(*Appendices continue*)

Table A2

Computational Measures of the Parameters Used to Compose Musical Motifs Varying in Balance, Contour, Symmetry, and Complexity, Which Constituted the Composite Measures

Attribute	Parameter	Computational measure	Composite measure
Balance	Event distribution	***Bisect unbalance***: Equilibrium between the two halves of a stimulus	BC1
	Climax position	***Center of mass offset***: Distance between center of mass and geometric center	
	Tension	***Event heterogeneity***: Heterogeneity in the temporal distribution of events	
Contour	Intervals	***Average absolute interval***: Average absolute pitch interval size	CC1
		Melodic abruptness: Average interval size of changes of direction per note	
		Durational abruptness: Proportion of the stimulus with changes of direction	
	Durations	***Rhythmic abruptness***: Average ratio of consecutive durations	CC2
Symmetry	Palindromic structure	***Total asymmetry***: Direct–retrograde accumulated pitch difference	SC1
		Asymmetry index: Proportion of the stimulus with asymmetries	
Complexity	Event density	***Event density***: Number of note events per time unit	KC1
	Event variety	***Average local pitch entropy***: Average pitch entropy of .25-s sliding windows	
	Predictability	***Pitch entropy***: Entropy of pitch distribution	
		2-tuple interval entropy: Entropy of 2-tuple interval distribution	
		Weighted permutation entropy: Permutation entropy considering the SD of the pitch distribution of each 3-note sequence	
		3-tuple duration entropy: Entropy of 3-tuple duration distribution	KC2

(*Appendices continue*)

Appendix B

Questionnaire

Original Spanish Version	Translated English Version
1. ¿Cuál es tu edad? (Respuesta numérica)	1. How old are you? (Numeric response)
2. ¿Cuál es tu género? Mujer/Hombre/Otro	2. What is your gender? Woman/Man/Other
3. ¿Cuál es el nivel de estudios más alto que has completado hasta la fecha? Secundaria/Bachillerato o equivalente/Grado, licenciatura o equivalente/Posgrado, máster o doctorado	3. What is the highest level of education you have ever attained? Secondary-high school or equivalent/Undergraduate/Graduate, Masters, or Ph.D.
4. ¿Cuál es el nivel de estudios musicales más elevado alcanzado hasta el momento? Enseñanza general obligatoria (primaria y secundaria)/Enseñanza elemental de música (escuela de música o conservatorio elemental)/Enseñanza profesional de música (conservatorio profesional)/Grado en música/Posgrado, máster o doctorado en música	4. What is the highest level of musical education you have ever attained? General education (primary and secondary)/Elementary musical education (music school or conservatory)/Professional musical education (music school or conservatory)/Bachelor in music/Postgraduate, Masters, or Ph.D. in music
5. ¿Durante cuántos años has recibido educación musical formal? (Respuesta numérica)	5. How many years have you received formal musical education? (Numeric response)
6. ¿A qué edad comenzó tu formación musical? (Respuesta numérica)	6. Please, specify your age at the onset of your formal musical training. (Numeric response)
7. ¿Te dedicas profesionalmente a la música? Sí/No	7. Are you a professional musician? Yes/No
8. ¿Cuánto te han gustado los motivos musicales en general? Por favor, valora del 1 (muy poco) al 5 (mucho).	8. How much did you like the musical motifs in general? Please, rate from 1 (*very little*) to 5 (*very much*).
9. ¿En qué te fijas o qué consideras más importante al juzgar la música estéticamente? Dicho de otro modo, ¿en qué crees que has basado tus valoraciones? (Respuesta abierta)	9. What do you take into consideration or believe most important when judging music aesthetically? In other words, what do you think you based your ratings upon? (Open response)

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IX

Evaluative Judgment Across Domains:

Liking Balance, Curvature, Symmetry and Complexity in Musical Motifs and Visual Designs

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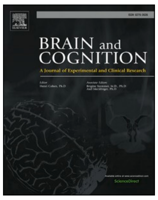

Evaluative judgment across domains: Liking balance, contour, symmetry and complexity in melodies and visual designs

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ABSTRACT

Evaluative judgment—i.e., assessing to what degree a stimulus is liked or disliked—is a fundamental aspect of cognition, facilitating comparison and choosing among alternatives, deciding, and prioritizing actions. Neuroimaging studies have shown that evaluative judgment involves the projection of sensory information to the reward circuit. To investigate whether evaluative judgments are based on modality-specific or modality-general attributes, we compared the extent to which balance, contour, symmetry, and complexity affect liking responses in the auditory and visual modalities. We found no significant correlation for any of the four attributes across sensory modalities, except for contour. This suggests that evaluative judgments primarily rely on modality-specific sensory representations elaborated in the brain's sensory cortices and relayed to the reward circuit, rather than abstract modality-general representations. The individual traits art experience, openness to experience, and desire for aesthetics were associated with the extent to which design or compositional attributes influenced liking, but inconsistently across sensory modalities and attributes, also suggesting modality-specific influences.

Evaluative judgment—assigning hedonic values to current and anticipated objects and events—is a fundamental feature of human cognition. Being able to evaluate stimuli as good or bad, liked or disliked, preferred or not, facilitates comparing and choosing among alternatives, deciding, and prioritizing actions (Berridge & Kringelbach, 2013; Pessiglione & Lebreton, 2015; Rangel, Camerer & Montague, 2008). People assign hedonic values to concrete and biologically relevant objects, such as food and other people's faces (Aharon et al., 2001; Kampe, Frith, Dolan, & Frith, 2001; O'Doherty et al., 2003; Winston, O'Doherty, Kilner, Perrett, & Dolan, 2007). But they also assign value to many kinds of abstract and cultural objects, from money to art (Blood & Zatorre, 2001; Erk, Spitzer, Wunderlich, Galley, & Walter, 2002; Harvey, Kirk, Denfield, & Montague, 2010; Kirk, Harvey, & Montague, 2011).

Neuroimaging evidence has shown that hedonic values are computed by the mesocorticolimbic reward circuit, a distributed system of brain regions including the nucleus accumbens, caudate nucleus, pallidum, amygdala, orbitofrontal cortex (OFC), anterior cingulate cortex (ACC), and insula (Bartra, McGuire, & Kable, 2013; Brown, Gao, Tisdelle, Eickhoff, & Liotti, 2011; Sescousse, Caldú, Segura, & Dreher, 2013). Reward signals computed by neurons in these structures assess the hedonic value of perceptual properties of objects relayed from sensory cortices (Becker et al., 2019; Berridge & Kringelbach, 2015; Skov, 2019). For instance, Salimpoor and colleagues (2013) collected blood oxygenation level–dependent activity while participants listened to excerpts of unfamiliar music and placed economic bids to hear them again. Their results showed that activity in the nucleus accumbens was the best predictor of the amount participants were willing to bid, and that functional connectivity between the nucleus accumbens and the primary and surrounding auditory cortices increased significantly when participants listened to the excerpts they found most desirable. In another study, Cheung and colleagues (2019) showed that musical pleasure

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arises from combinations of the uncertainty of perceivers' musical expectations and their surprise when musical events deviate from those expectations: musical pleasure is greatest when events are highly surprising in a low-uncertainty context, or when events are not very surprising in a high-uncertainty context. Moreover, the interaction between uncertainty and surprise was related to brain activity in the amygdala, hippocampus, and auditory cortex.

Evaluative judgment, therefore, involves the integration of information about perceptual attributes (e.g., tonal pattern processing in the auditory domain, or contour and symmetry processing in the visual domain) and about hedonic attributes (e.g., reward prediction, reward value). This interaction between sensory and hedonic processes is so crucial, that sensory information that is not relayed to these nuclei in the reward circuit fails to acquire hedonic value. This is the case with Specific Musical Anhedonia (SMA), the inability to experience pleasure from music. Diffusion tensor imaging studies show that people with SMA have reduced white matter connectivity between auditory brain regions and the ventral striatum, a key region of the brain's reward circuit (Sachs, Ellis, Schlaug, & Loui, 2016). Even in people without SMA, individual sensitivity to musical pleasure correlates with differences in connectivity between the auditory cortex and the reward circuit (Loui et al., 2017; Martínez-Molina, Mas-Herrero, Rodríguez-Fornells, Zatorre, & Marco-Pallarés, 2016).

This integration of sensory and hedonic information is not only crucial to the computation of hedonic values; it also marks the distinction between different sorts of hedonic values. The same reward circuit is involved in the pleasurable experiences we get from many sources, including music, food, and drugs (Levy & Glimcher, 2012; Mallik, Chandra, & Levitin, 2017; Nadal & Skov, 2018). What distinguishes those pleasures from each other is the sort of sensory information that is relayed to the reward circuit and the path it is relayed along (Mas-Herrero, Maini, Sescousse, & Zatorre, 2021).

How do perceptual attributes trigger the process of hedonic valuation? A thorough account is only coming into focus (Skov, 2020; Skov & Nadal, 2021). Multiple studies have shown that perceptual properties such as balance, contour, symmetry, or complexity affect liking for visual stimuli (Leder & Nadal, 2014; Pelowski, Markey, Lauring, & Leder, 2016). Findings from these studies indicate that most people prefer balanced, smooth, symmetric, and complex visual designs (Bertamini, Palumbo, Gheorghes, & Galatsidas, 2016; Jacobsen & Höfel, 2003; Jacobsen & Höfel, 2001; Nadal, Munar, Marty, & Cela-Conde, 2010; Wilson & Chatterjee, 2005). However, a growing number of experiments have demonstrated that such group-level effects mask remarkable individual differences (Corradi et al., 2019; Corradi, Chuquichambi, Barrada, Clemente, & Nadal, 2020; Jacobsen, 2004; Jacobsen & Höfel, 2002). For example, in contrast to general trends, some people prefer visual designs with low balance, jagged contours, asymmetry, or simplicity (e.g., Leder et al., 2019).

Understanding differences in the way people value objects is crucial to understanding the process of valuation itself. One of the ways in which people differ in liking is the extent to which they take into account certain object features. Corradi and colleagues (2020) showed that people differ in the extent to which they rely on balance, contour, symmetry, and complexity when deciding about how much they like visual designs, and that these differences are stable in time. While most people were sensitive to those features, in the sense that they determined people's liking—i.e., they liked balanced, smooth, symmetric, and complex objects, or unbalanced, jagged, asymmetric, and simple objects most— some were indifferent to one or more of these features—in the sense that their liking ratings were unrelated to those features (Corradi et al., 2020). Furthermore, Corradi and colleagues (2019) showed that this individual sensitivity to particular stimulus features, at least to visual contour, seems to be consistent across kinds of visual objects: People who liked real objects with jagged contours also tended to like abstract designs with jagged contours, whereas people who were indifferent to contour for one kind of visual object also tended to be indifferent to the other kind.

Results from a comparable study with musical stimuli showed that people also vary considerably in their aesthetic sensitivity to auditory features and that musical aesthetic sensitivities are also stable in time (Clemente, Pearce, & Nadal, 2021). Clemente and colleagues (2020) created four sets of 50 short melodies varying either in balance, contour, symmetry, or complexity, and asked participants to listen to and rate their liking for each of them (Clemente et al., 2021). Their results showed that, as a group, participants liked more unbalanced, melodically jagged, rhythmically smooth, asymmetric, and melodically complex melodies—note that in these and the present studies, *melodic* contour and complexity refer to *pitch-related* contour and complexity, respectively. However, together with these general trends, and in line with Corradi and colleagues' (2020) results, they also found considerable variation among participants in the extent to which musical balance, contour, symmetry, and complexity influenced people's liking, and that these differences were stable in time (Clemente et al., 2021).

Here, we investigated whether aesthetic sensitivity, defined as the extent to which specific stimulus features influence someone's liking, holds across the visual and auditory modalities. For example, is someone's liking determined by complexity, regardless of the sensory modality? Or is it the case that complexity might influence liking in the visual but not the music domain, or vice versa? Finding that people have common aesthetic sensitivities to musical and visual complexity, for instance, would suggest that the basis for the computation of hedonic value by the reward system is a modality-general representation of complexity—i.e., an abstraction of the common features contributing to musical and visual complexity. Information density is a plausible candidate for this kind of modality-general representation. If the reward system operates on this sort of modality-general representations, then information-dense stimuli should be liked or disliked to a similar degree irrespective of whether they are visual or auditory.

On the other hand, finding that people have different aesthetic sensitivities to musical and visual complexity would suggest that the basis for the computation of hedonic value by the reward system is a modality-specific representation of complexity—i.e., a representation of the auditory features that contribute specifically to musical complexity, such as expectation in tonal sequences (Cheung et al., 2019; Gold, Pearce, Mas-Herrero, Dagher, & Zatorre, 2019; Salimpoor, Zald, Zatorre, Dagher, & McIntosh, 2015), the degree of rhythmic syncopation or chord dissonance (Matthews, Witek, Heggli, Penhune, & Vuust, 2019), or a representation of the visual features that contribute specifically to visual complexity, such as the number and heterogeneity of angles in a figure, variety of colors, or irregular spatial arrangements (Nadal et al., 2010). If the reward system operates on such modality-specific representations, liking for visual complexity should be unrelated to liking for auditory complexity because the nature of the cues that drive liking for one and the other is substantially different. The same could be said about other features like balance, contour, and symmetry.

In sum, hedonic liking is computed by reward-related processes in mesocorticolimbic reward circuit operating on information about stimulus attributes relayed from sensory cortices. But what sort of attributes are these? Here we aim to clarify whether the information about the stimuli that the reward system relies upon resembles an abstract modality-general representation—e.g., information density—, or a concrete modality-specific representation—e.g., number and variety of angles or spatial arrangement of parts in a visual design, and tonal sequence predictability or rhythmic syncopation in a melody. To examine these alternatives, we tested whether aesthetic sensitivity to visual balance, contour, symmetry, and complexity correlate with aesthetic sensitivity to musical balance, contour, symmetry, and complexity. Specifically, we obtained liking ratings for visual and auditory stimuli varying systematically in balance, contour, symmetry, and complexity. We then examined whether individual aesthetic sensitivity profiles for these attributes show any correspondence across the two modalities.

Evaluative judgments of visual art and design and music are modulated by domain expertise in visual art and design (Belke, Leder, & Augustin, 2006; Pang, Nadal, Müller-Paul, Rosenberg, & Klein, 2013) and music (Lahdelma & Eerola, 2020; Popescu et al., 2019), respectively, art interest and knowledge (Silvia, 2005; Specker et al., 2020), desire for aesthetics (Lundy, Schenkel, Akrie, & Walker, 2010), and personality traits such as openness to experience (Chamorro-Premuzic, Reimers, Hsu, & Ahmetoglu, 2009; Furnham & Chamorro-Premuzic, 2004) and need for cognitive closure (Ostrofsky, & Shobe, 2015; Wiersema, van der Schalk, & van Kleef, 2012). Therefore, to explore potential factors underlying individual differences in aesthetic sensitivities, we also examined influences of various personality measures, including interest and knowledge in music and visual art, openness to experience, need for cognitive closure, and desire for aesthetics.

1. Method

1.1. Participants

Forty-eight self-reported non-experts in music and visual art (26 female, 22 male, aged between 18 and 29 years, $M = 22.72$, $SD = 3.09$) took part in the study. All participants reported normal or corrected-to-normal vision and hearing and no cognitive impairments. All participants were students at the University of the Balearic Islands. Participants were unaware of the purpose of the study and provided written informed consent before participating. The study was conducted following the Declaration of Helsinki and received approval from the Committee for Ethics in Research of the Balearic Islands (approval number IB 3573/17 PI).

1.2. Procedure

Participants undertook the experimental tasks in the Laboratory of Psychology of the University. They were first welcomed and briefed about the entire procedure. Each participant was then asked to enter one of the individual sound-attenuated testing cabins, all of which had the same computers, software, adequate light conditions, and headphone sets. In the testing cabin, participants received the same standard verbal and onscreen instructions. Participants sat approximately 45 cm from the screen and self-regulated their headsets' volume at the beginning of the auditory task. The whole experiment was performed through Open Sesame (Mathôt, Schreij, & Theeuwes, 2012).

Participants rated their liking for 66 visual designs and 96 melodies varying in balance, contour, symmetry, or complexity, presented one at a time. Ratings were self-paced and given on a 1–5 Likert scale anchored by *not at all* (1) to *very much* (5). Participants were requested to base their responses on the subjective feelings of pleasure, interest, enjoyment, and desirability evoked or elicited by the stimulus, and allowed to repeat each auditory stimulus before rating it. The order of visual and auditory tasks was counterbalanced between participants, and the stimuli were individually randomized. After completing the tasks, participants completed five computer-based questionnaires. The experimental session lasted between 30 and 40 min.

1.3. Materials

For the visual task, we used the same three sets of b/w abstract designs as in Corradi et al. (2020). The first was a set of 22 stimuli designed by Wilson and Chatterjee (2005), which we used to assess aesthetic appreciation of visual balance (Fig. 1, first column). They consist of diverse configurations of seven hexagons of different sizes varying in balance (*unbalanced–balanced*), measured as the average of eight symmetry components over the image's axes. The second was a set of 24 stimuli, designed following Bertamini and colleagues' (2016) guidelines, to assess aesthetic sensitivity to visual contour (Fig. 1, second column). Half of them had *smooth* contours—defined by cubic splines linking the figure's vertexes—, and the other half had *jagged* contours—defined by straight lines linking the figure's vertexes. To incorporate some variability in the stimuli, we included equal numbers of figures with 22 and 26 vertices, and the same number of designs created from *circles*, *ovals*, and *lobed ovals*. The third set was composed of 20 of Jacobsen and Höfel's (2002) stimuli. These stimuli were designed as a series of solid black circles with a centered white square containing triangles arranged to form designs varying in mirror symmetry (Fig. 1, third column)—i.e., with respect to vertical, horizontal, and diagonal axes—and complexity (Fig. 1, fourth column)—defined as the number of elements. We chose ten *symmetric* and ten *asymmetric* stimuli matched for different degrees of complexity, corresponding to the number of constituent elements (*simple–complex*). The image sizes of all visual stimuli were 450 pixels on a 1920 × 1080 computer screen of 21″.

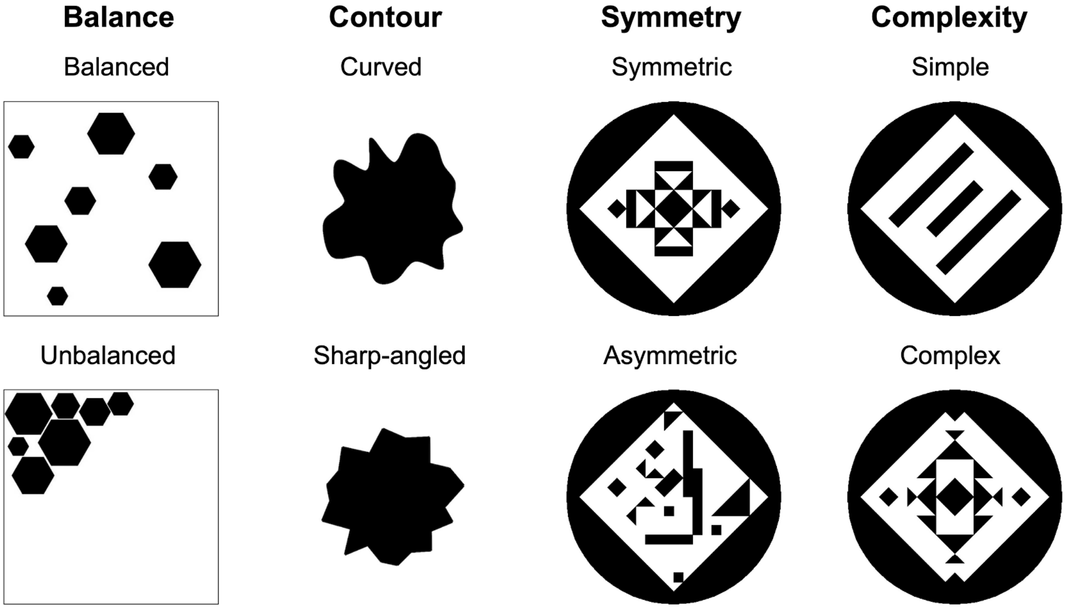

Fig. 1. Examples of visual stimuli designed by Wilson & Chatterjee (2005) for balance (first column), Bertamini et al. (2016) for contour (second column), and Jacobsen & Höfel (2002) for symmetry and complexity together (third and fourth columns).

For the auditory task, we used Clemente et al.'s (2020) MUST abridged stimulus set, the same as in Clemente et al. (2021). These musical stimuli are 4-second monophonic piano-like melodies in C-Major (Fig. 2) with the same musical idiom and acoustic features, expressly composed for empirical studies and designed to combine experimental control and musical appeal. The MUST set comprises four subsets of melodies that vary in either balance, contour, symmetry, or complexity. The parameters of variation in each subset are analogous to those used to generate the visual sets (Clemente et al., 2020): Balance was defined as the homogeneity of the event distribution across the melody and the central position of the climax for *balanced* melodies, and the accumulation of events at either end of the melody for *unbalanced* ones. Melodic contour was defined by the interval width, with wider and more varied intervals for melodically *jagged* melodies and rhythmic contour was determined by the presence of sudden rhythmic changes for rhythmically *jagged* melodies, and smaller melodic and rhythmic intervals for *smooth* melodies. Symmetry was defined as the mirror-reversed melodic correspondence from the midpoint of each stimulus. *Symmetric* melodies are musical palindromes (i.e., they have a mirror reflection structure): the second half is a literal retrograde repetition of the first half—e.g., A(B)A, ABC(C)BA. A*symmetric* melodies are not musical palindromes: they lack such retrograde repetition. Thus, the only form of symmetry considered here is temporal mirror symmetry. Finally, complexity was defined by the number and variety of events or notes. *More complex* melodies have many notes varying widely in duration, pitch interval size, and register. Conversely, *simpler* melodies have a small number of highly predictable notes with repeated uncomplicated patterns. To minimize variation in all attributes other than the intended one, all melodies in the Balance subset are asymmetric, have mild contours, and overall medium complexity; those in the Contour subset are balanced, asymmetric, and with overall medium complexity; those in the Symmetry subset are balanced and have mild contours and overall medium complexity; and the stimuli in the Complexity subset are symmetric, balanced, and with mild contours.

The temporal nature of music could make processing the musical stimuli more challenging than processing the visual stimuli, especially in the case of symmetry, which involves comparing two mirror-reversed halves of a melody. To facilitate the processing of each of these musical features, Clemente et al. (2020) minimized variation in all parameters not contributing directly to the structural feature of interest, kept tonal and harmonic relationships simple and homogeneous, and used brief stimuli. Thus, all stimuli were composed using the same musical idiom, including language and style (Western tonal-functional), key (C Major), texture (monophonic), timbre (piano-sampled; Garritan Sound Library for Finale, MakeMusic), duration (4 s), overall and instantaneous loudness (no changes in musical dynamics or spatial cues), and other acoustical properties, avoiding expressive performance and recording inconsistencies and variability (Clemente et al., 2020). Even if the perception of musical symmetry is more demanding (e.g., working-memory load) than that of visual symmetry, Clemente et al. (2020) showed that the stimuli were correctly perceived and categorized well above chance.

Following Clemente et al.'s (2021) approach, we used the abridged set, which includes the 12 most extreme stimuli in each pole for which the agreement in perceptual judgments was maximal (Clemente et al., 2020). During the analyses, we found that two pairs of the stimuli belonging to the Symmetry and Complexity abridged subsets were unintentionally duplicated: S4 = K8 and S5 = K9. Their presentation order did not influence ratings significantly (all *ps* > 0.050 in the *t*-tests of block order for each stimulus, meaning no effects of familiarity), so including them in the analyses would not affect the direction of the results. However, to be sure of no adverse impact, we decided to exclude them from the present analyses, leaving us with 12 *balanced* – 12 *unbalanced,* 12 *smooth* – 12 *jagged*, 10 *symmetric* – 12 *asymmetric*, and 10 *simple* – 12 *complex*. The melodies were presented in WAV format through headphones. The MUST (Clemente et al., 2020) also includes
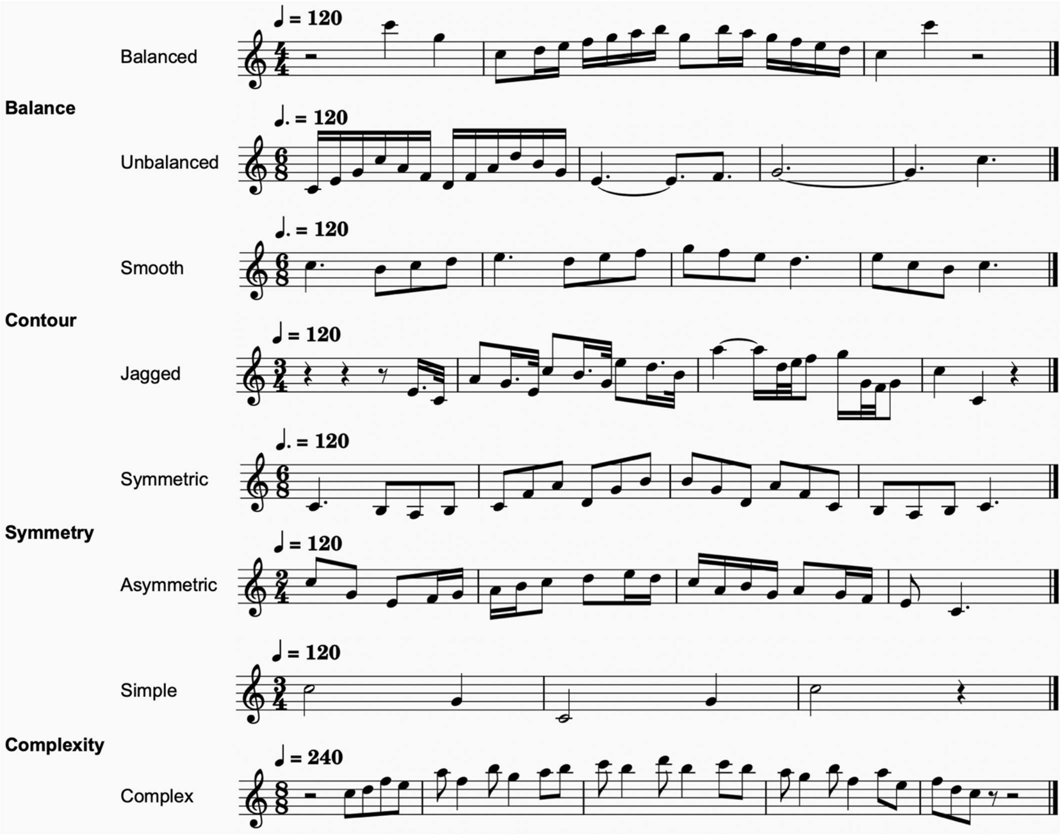
Fig. 2. Sample scores of musical stimuli in each subset.

composite computational measures specific for the characteristic structural properties of each subset: Balance and symmetry were defined by single composite measures of balance (BC1) and symmetry (SC1), respectively. Two components quantified the structural parameters of contour: one for melodic (pitch-related) contour (CC1) and the other for rhythmic contour (CC2). Likewise, two components quantified complexity: a measure of melodic complexity KC1 (encompassing event density and pitch-related entropy) and a measure of rhythmic complexity KC2 (duration entropy). Higher values in these composite measures correspond to lower balance and greater jaggedness, asymmetry, and complexity, respectively.

Participants also responded to five questionnaires. The first addressed the demographic traits age, sex, academic degree, formal artistic education, professionalization, and expertise in music and visual art. Following Corradi et al. (2020), the second was adapted from the Art experience questionnaire (AEQ; Chatterjee, Widick, Sternschein, Smith II, & Bromberger, 2010) on art interest and knowledge. The third was the Openness to experience scale (NEO-FFI-R; McCrae & Costa, 2004). The fourth consisted of the first 12 items of the Spanish adaptation of the Need for cognitive closure scale (NCC; Horcajo, Díaz, Gandarillas, & Briñol, 2011). The experiment concluded with an abridged, adapted, and translated version of the Desire for aesthetics scale (DFAS; Lundy et al., 2010). The items in our AEQ and DFAS versions were also reformulated for the music domain. Except for the NCC, the questionnaires were translated (AEQ, Openness, DFAS) into Spanish or written in Spanish (demographic) by the first author. The adapted questionnaires are available in the Appendix.

1.4. Data analysis

1.4.1. Individual aesthetic sensitivities.

Following Corradi et al. (2020) and Clemente et al. (2021), we fitted linear mixed-effects models (Hox, Moerbeek, & van de Schoot, 2010; Snijders & Bosker, 2012) to assess the effect of the main predictors on participants' liking judgments for the stimuli in each visual and musical set. The models were set up to reflect each set's main predictors on participants' responses. In all cases, we followed Barr, Levy, Scheepers, and Tily's (2013) suggestion to model the maximal random-effects structure justified by the experimental design. This avoids the loss of power, reduces type I error, and enables the generalizability of results to other participants and stimuli.

The model of liking for visual balance included Wilson and Chatterjee's (2005) objective balance index for each visual design as a fixed effect. It also included intercept and slope for balance as random effects within participants. The model of liking for visual contour included the interaction between contour (*smooth, jagged*), shape (circle, oval, lobed oval), and vertices (22, 26) as fixed effects. It also included intercept and slope for each of these features and their interactions as random effects within participants. The model of liking for visual symmetry (*symmetric, asymmetric*) and complexity (number of elements) included the interaction between both features. It also included intercept and slope for both of these features and their interaction as random effects within participants. The model of liking for musical balance included the MUST composite measure of balance (BC1) as a fixed effect. It also included intercept and slope for BC1 as a random effect within participants. The model of liking for musical contour included the interaction between the MUST composite measures of melodic (CC1) and rhythmic (CC2) contour as fixed effects. It also included intercept and slope for both of these measures and their interaction as random effects within participants. The model of liking for symmetry included the MUST composite measure of asymmetry (SC1) as a fixed effect. It also included intercept and slope for SC1 as a random effect within participants. Finally, the model of liking for musical complexity included the interaction between the MUST composite measures of melodic (KC1) and rhythmic (KC2) complexity as fixed effects. It also included intercept and slope for both of these measures and their interaction as random effects within participants.

All models also included random intercepts within stimuli. Continuous predictors were mean-centered to allow comparisons with categorical variables. Categorical predictors were deviation-coded using the *contrasts()* function in the 'stats' package (R Core Team, 2020), ranging from -0.5 to 0.5. Reference levels (i.e., -0.5) for the categorical variables were: *man* for gender; *jagged, lobed oval,* and *22 vertices* in the model of visual contour; and *asymmetric* in the model of visual symmetry.

Our primary aim was to understand individual differences in responsiveness to structural properties driving liking. In linear mixed-effects models, this corresponds to the individual slope estimated from the models' random-effect structure, which we take as our aesthetic sensitivity measure. We used it to describe individual aesthetic sensitivity to visual balance, contour, symmetry, and complexity, and to musical balance, melodic and rhythmic contour, musical symmetry, and melodic and rhythmic complexity to study the relationships between these sensitivities. Shapiro–Wilk tests were used to assess the distributions' normality.

All analyses were carried out within the R environment for statistical computing, R version 4.0.3 (R Development Core Team, 2020). We used the *lmer()* function of the 'lme4′ package (Bates, Maechler, Bolker, & Walker, 2015) and the 'lmerTest' package (Kuznetsova, Brockho, & Christensen, 2012) to estimate the *p*-values for the *t*-tests based on the Satterthwaite approximation for degrees of freedom, which produces acceptable type I error rates (Luke, 2017). Effect sizes of each factor in the models were calculated with the function *effectsize()* of the 'effectsize' package (Ben-Sachar, Makowski, & Lüdecke, 2020). To interpret the effect sizes, we followed Chin's (1998) method. Semi-partial coefficients of determination (r^2) were computed for each fixed effect in the mixed models with the *r2beta()* function of the 'r2glmm' package (Jaeger, 2017). For their interpretation, we followed Gignac and Szodorai's (2016) recommendations.

1.4.2. Relations between visual and auditory aesthetic sensitivities.

Spearman's correlations were used to ascertain the relationships between aesthetic sensitivities to the same attribute across sensory modalities. We preferred a non-parametric test given the significant results in the Shapiro-Wilk tests regarding the distributions of aesthetic sensitivities derived from the linear mixed-effects models.

1.4.3. Relations between aesthetic sensitivities and other traits

Multiple linear-regression analyses were used to explore the degree to which interest and knowledge in visual art and music, openness to experience, need for cognitive closure, and desire for aesthetics explained between-subject variance in aesthetic sensitivity. Given that we did not have any specific hypothesis or expect the demographic variables to affect sensitivity, this part of the analysis was exploratory. Continuous predictors were centered and scaled using the *scale()* function in the 'base' R package. To compute and interpret effect sizes for each predictor, we used the same function and criteria as for the linear mixed-effects models described above. The partial η2 describes the proportion of total variation attributable to a given factor, partialling out (i.e., excluding) other factors from the total non-error variation. For this, we used the *etasq()* function of the 'heplots' package (Fox, Friendly, & Monette, 2008).

2. Results

2.1. Individual aesthetic sensitivities

2.1.1. Models of visual liking

Visual balance. Visual balance did not significantly influence overall liking ratings (Table 1, Fig. 3A), with very small effect size and very weak semi-partial r^2. The individual slopes of liking for balance ranged from −0.071, indicating greater liking for lower balance, to 0.056,

Table 1

Linear Mixed-effects Models for each Attribute in the Visual and Musical Domains.

Modality	Model	Predictor	*b*	ß	*df*	*t*	*p*	*d* [95% CI]	r^2 [95% CI]
Visual	**Balance**	**VB**	0.008	0.128	55.802	1.897	0.063	0.13 [0.00, 0.26]	0.02 [0.01, 0.04]
	Contour	**VC**	0.729	0.626	36.447	5.683	< 0.001	0.63 [0.41, 0.84]	0.10 [0.07, 0.13]
	Symmetry* Complexity	**VS**	0.910	0.728	46.498	6.391	< 0.001	0.73 [0.50, 0.95]	0.14 [0.10, 0.18]
		VK	0.032	0.155	27.973	3.623	0.001	0.15 [0.07, 0.24]	0.03 [0.01, 0.05]
		VS*VK	0.030	0.148	19.964	1.948	0.066	0.15 [0.00, 0.30]	0.01 [0.00, 0.02]
Auditory	**Balance**	**BC1**	−0.267	−0.246	29.724	−3.856	< 0.001	−0.25 [-0.37, −0.12]	0.06 [0.04, 0.09]
	Contour	**CC1**	0.166	0.144	33.600	1.824	0.077	0.14 [-0.01, 0.30]	0.02 [0.01, 0.04]
		CC2	−0.109	−0.115	21.190	−1.123	0.274	−0.11 [-0.32, 0.09]	0.01 [0.000, 0.02]
		CC1*CC2	−0.077	−0.081	20.440	−1.240	0.229	−0.08 [-0.21, 0.05]	0.01 [0.00, 0.02]
	Symmetry	**SC1**	0.203	0.196	19.870	2.979	0.007	0.20 [0.07, 0.33]	0.04 [0.02, 0.07]
	Complexity	**KC1**	0.315	0.333	42.037	4.486	< 0.001	0.33 [0.19, 0.48]	0.07 [0.04, 0.10]
		KC2	−0.092	−0.078	25.515	−1.522	0.140	−0.08 [-0.18, 0.02]	0.01 [0.00, 0.02]
		KC1*KC2	−0.085	−0.092	18.427	−1.987	0.062	−0.09 [-0.18, 0.00]	0.01 [0.00, 0.02]

Note. The predictors of individual liking ratings in the linear mixed-effects models are visual balance (VB), visual contour (VC), visual symmetry (VS), number of visual elements (VK), musical balance (BC1), melodic contour (CC1), rhythmic contour (CC2), musical symmetry (SC1), melodic complexity (KC1), and rhythmic complexity (KC2). *b* refers to the estimated group-level slope, ß to the standardized beta coefficient, *df* to the degrees of freedom, *t* to the *t*-value, *p* to the *p*-value, *d* to the effect size, and r^2 to the semi-partial coefficient of determination of each parameter to the model.

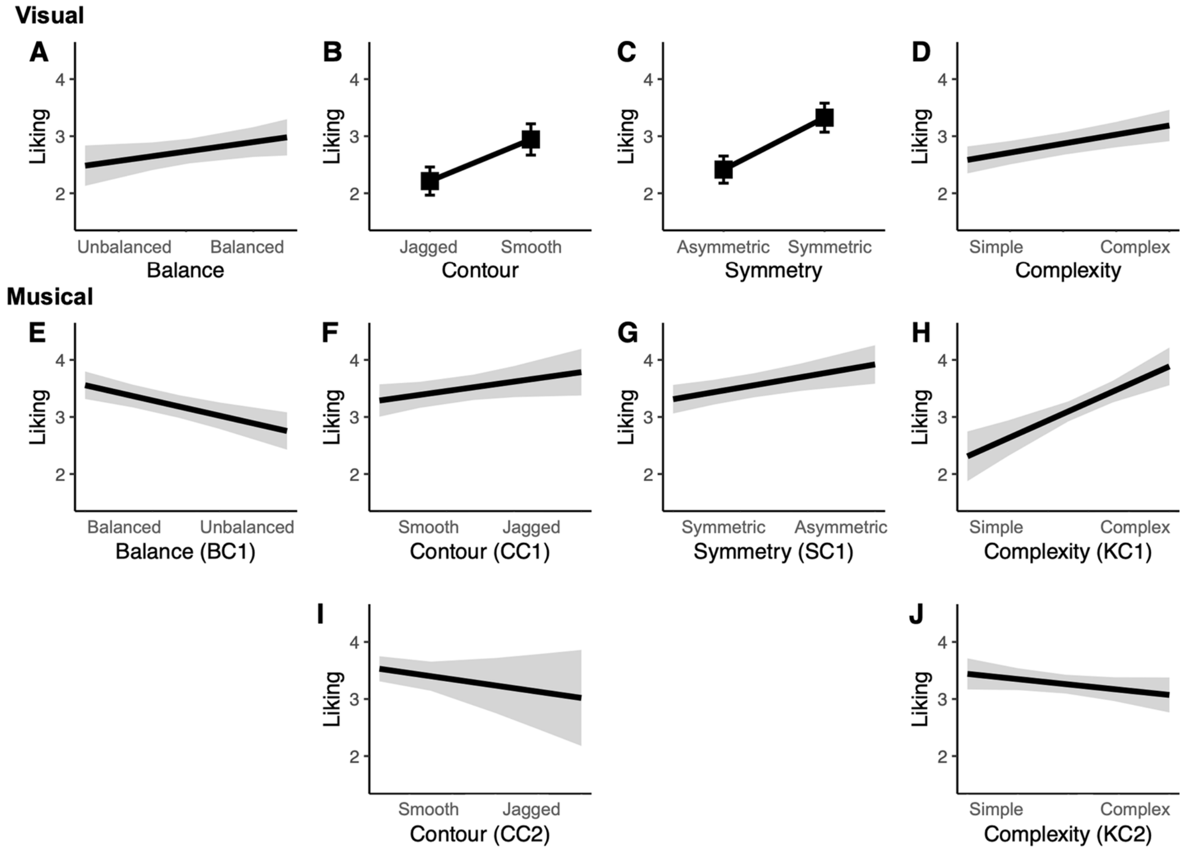

Fig. 3. Main effects on participants' liking for (A) visual balance, (B) visual contour, (C) visual symmetry, (D) visual complexity, (E) musical balance, (F) melodic contour, (G) musical symmetry, (H) melodic complexity, (I) rhythmic contour, and (J) rhythmic complexity. Higher values mean more balanced (VB), smooth (VC), symmetric (VS), and more complex (VK) images; and less balanced (BC1), more melodically (CC1) and rhythmically (CC2) jagged, asymmetric (SC1), and melodically (KC1) and rhythmically (KC2) complex melodies, respectively. Gray ribbons correspond to 95% CI.

indicating greater liking for higher balance, and were normally distributed (Table 2, Fig. 4A).

Visual contour. Overall, participants liked more smooth images (Table 1, Fig. 3B), with large effect size and very weak semi-partial r^2. Shape, number of vertices, and their interactions did not show significant effects (all *ps* > 0.100). The slopes of liking for contour ranged from −0.131, indicating greater liking for jagged figures, to 2.730, indicating greater liking for smooth designs, and were not normally distributed (Table 2, Fig. 4B).

Visual symmetry and complexity. Overall, participants liked more symmetric images (Table 1, Fig. 3C), with large effect size and very weak semi-partial r^2, and liking increased with complexity (Table 1, Fig. 3D), with very small effect size and very weak semi-partial r^2. No significant interaction between symmetry and complexity was found (Table 1), with very small effect size and very weak semi-partial r^2. The slopes of liking for symmetry ranged from −0.470, indicating greater liking for asymmetry, to 2.652, indicating greater liking for symmetry, and were normally distributed (Table 2, Fig. 4C). The slopes of liking for

Table 2
Distributions of Individual Slopes of Liking for Images and Music.

Sensory modality	Model	Predictor	*M*	*SD*	Shapiro–Wilk Tests			
					W	*p*	Skew	Kurtosis
Visual	Balance	VB	0.008	0.024	0.969	0.233	–	–
	Contour	VC	0.729	0.586	0.940	0.016	0.971	1.149
	Symmetry* Complexity	VS	0.910	0.702	0.974	0.362	–	–
		VK	0.032	0.027	0.948	0.033	0.484	2.001
Auditory	Balance	BC1	−0.267	0.145	0.964	0.144	–	–
	Contour	CC1	0.166	0.279	0.988	0.891	–	–
		CC2	−0.109	0.090	0.952	0.048	−0.293	−0.924
	Symmetry	SC1	0.203	0.010	0.973	0.330	–	–
	Complexity	KC1	0.315	0.303	0.925	0.004	−1.002	0.940
		KC2	−0.092	0.140	0.981	0.618	–	–

Note. The predictors of individual liking ratings in the linear mixed-effects models are visual balance (VB), visual contour (VC), visual symmetry (VS), number of visual elements (VK), musical balance (BC1), melodic contour (CC1), rhythmic contour (CC2), musical symmetry (SC1), melodic complexity (KC1), and rhythmic complexity (KC2). *M* refers to the mean slope, *SD* to the standard deviation, *W* to the *t*-value of the Shapiro–Wilk test, and *p* to its *p*-value. Skewness and kurtosis are reported when $p < .050$.

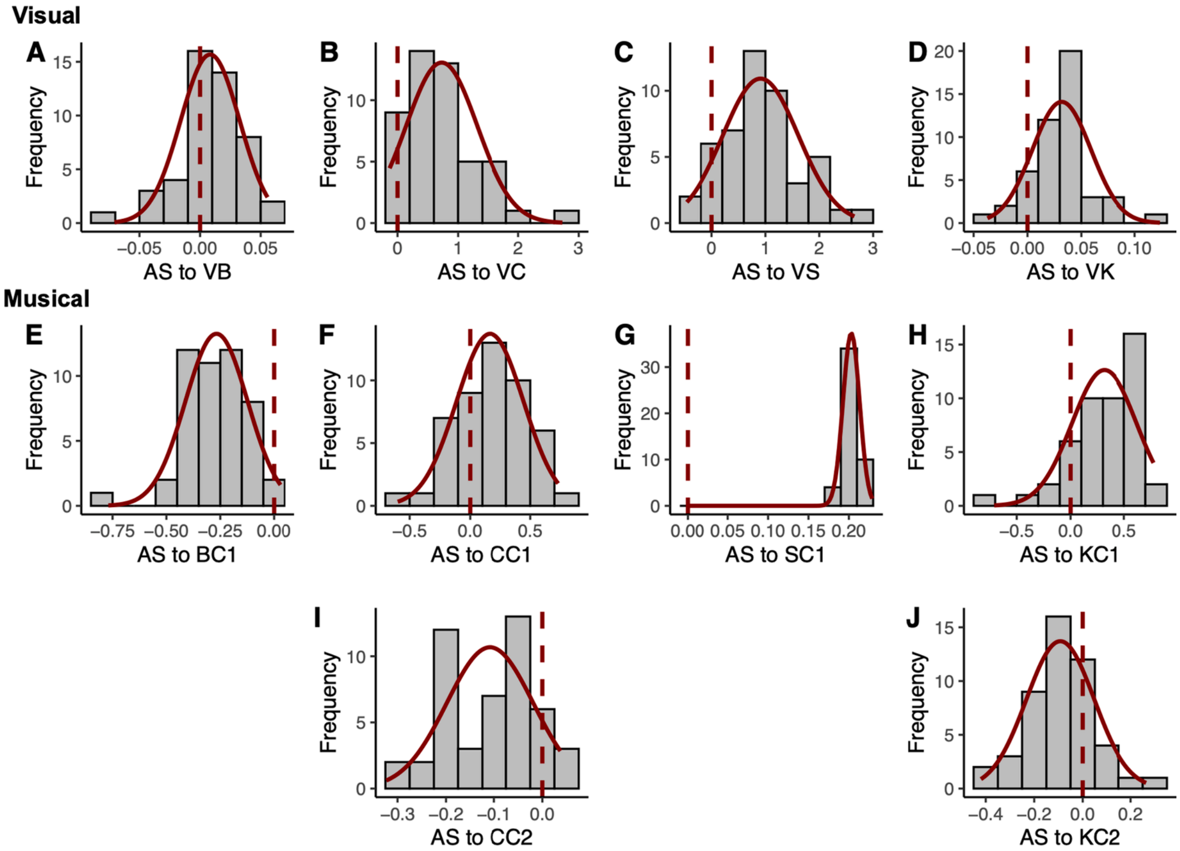

Fig. 4. Aesthetic sensitivity (AS) to visual and musical attributes: histograms of individual slopes of liking for (A) visual balance, (B) visual contour, (C) visual symmetry, (D) visual complexity, (E) musical balance, (F) melodic contour, (G) musical symmetry, (H) melodic complexity, (I) rhythmic contour, and (J) rhythmic complexity. Vertical dashed lines correspond to a slope of 0, meaning complete indifference, irresponsiveness, or insensitivity towards each structural property concerning liking judgments. Positive slopes indicate higher liking for more balanced (VB), smooth (VC), symmetric (VS), and more complex (VK) images; and less balanced (BC1), more melodically (CC1) and rhythmically (CC2) jagged, asymmetric (SC1), and melodically (KC1) and rhythmically (KC2) complex melodies, respectively. Negative slopes indicate higher liking for less balanced (VB), more jagged (VC), asymmetric (VS), and simple (VK) images; and more balanced (BC1), melodically (CC1) and rhythmically (CC2) smooth, symmetric (SC1), and melodically (KC1) and rhythmically (KC2) simple melodies, respectively. Fitted curves are outlined, although note that individual slopes of liking for visual contour and complexity, rhythmic contour (CC2), and melodic complexity (KC1) are not normally distributed.

complexity ranged from −0.037, indicating greater liking for simplicity, to 0.123, indicating greater liking for complexity, and were not normally distributed (Table 2, Fig. 4D).

2.1.2. Models of auditory liking

Musical balance. Overall, liking increased with increasing balance (Table 1, Fig. 3E) with small effect size and very weak semi-partial r^2. The individual slopes ranged from −0.769, indicating greater liking for balance, to 0.029, indicating greater liking for lack of balance, and were normally distributed (Table 2, Fig. 4E).

Musical contour. Overall, liking judgments were not significantly predicted by either melodic contour (Table 1, Fig. 3F), rhythmic contour

(Table 1, Fig. 3I), or their interaction (Table 1), all with very small effect size and very weak semi-partial r^2. The slopes for melodic contour ranged from −0.598, indicating greater liking for smooth melodic contours, to 0.730, indicating greater liking for jagged melodic contours, and were normally distributed (Table 2, Fig. 4F). The slopes for rhythmic contour ranged from −0.323, indicating greater liking for smooth rhythms, to 0.037, indicating greater liking for jagged rhythms, and were not normally distributed (Table 2, Fig. 4I).

Musical symmetry. Participants liked more asymmetric melodies (Table 1, Fig. 3G) overall, with small effect size and very weak semi-partial r^2. The slopes ranged from 0.184 to 0.229, indicating greater liking for asymmetry, and were normally distributed (Table 2, Fig. 4G).

Musical complexity. Overall, liking increased with melodic complexity (Table 1, Fig. 3H), with small effect size and very weak semi-partial r^2. The effect of rhythmic complexity was not significant (Table 1, Fig. 3J), and the interaction between melodic and rhythmic complexity verged on significance (Table 1), both with very small effect sizes and very weak semi-partial r^2. The slopes for melodic complexity ranged from −0.709, indicating greater liking for melodic simplicity, to 0.775, indicating greater liking for melodic complexity, and were not normally distributed (Table 2, Fig. 4H). The slopes for rhythmic complexity ranged from −0.420, indicating greater liking for rhythmic simplicity, to 0.264, indicating greater liking for rhythmic complexity, and were normally distributed (Table 2, Fig. 4J).

2.2. Relations between sensitivities to the same attribute across sensory modalities

We found only one significant correlation between aesthetic sensitivities to the same attribute in the two sensory modalities (Table 3): aesthetic sensitivity to melodic contour correlated significantly with aesthetic sensitivity to visual contour (ρ = -0.422, p = .003). This indicates that participants who liked more smooth melodies also tended to like more smooth visual designs.

2.3. Relations between aesthetic sensitivities and other traits

We ran one multiple regression analysis for each structural property to determine whether visual art interest and knowledge (visual AEQ), musical interest and knowledge (musical AEQ), openness to experience (OTE), need for cognitive closure (NCC), and desire for aesthetics (DFAS) accounted for differences in aesthetic sensitivity between participants.

Interest and knowledge in visual art was the only significant predictor of aesthetic sensitivity to visual balance, with medium effect size (b = -0.012, ß = −0.477, t = -2.917, p = .006, d = -0.48 [-0.82, −0.15], partial η^2 = 0.168), and complexity, with large effect size (b = 0.017, ß = 0.633, t = 4.241, p < .001, d = 0.64 [0.34, 0.94], partial η^2 = 0.300). Namely, people with higher art interest and knowledge also tended to like less balanced (Fig. 5A) and more complex designs (Fig. 5B). Regarding musical aesthetic sensitivities, there was a significant relation between aesthetic sensitivity to musical balance and openness to experience with medium effect size (b = -0.057, ß = −0.395, t = -2.423, p = .020, d = -0.40 [-0.73, −0.07], partial η^2 = 0.123): liking for balanced music tended to increase with openness to experience (Fig. 5C). No other significant results were found. Together, the predictors explained between 1 and 27% of the variability in the models of aesthetic sensitivities.

3. Discussion

Evaluative judgments of many different kinds of objects entail the assessment of the hedonic value of their perceptual attributes (Berridge & Kringelbach, 2015; Pessiglione & Lebreton, 2015; Skov, 2020). Hedonic values arise from activity in the mesocorticolimbic reward circuit and sensory brain regions that integrates information about perceptual and hedonic attributes. These mechanisms give rise to the anticipation and enjoyment of art, food, and drugs (Levy & Glimcher, 2012; Mallik, Chandra, & Levitin, 2017; Nadal & Skov, 2018). The relay of sensory information to the reward circuit is not only crucial to the generation of hedonic value. The sort of information that is relayed, and the path it follows, marks the difference between the enjoyment of different kinds of objects (Mas-Herrero et al., 2021).

If the way sensory information is conveyed to the reward circuit plays such a key role in determining evaluative judgments, it is important to understand what sort of sensory attributes are conveyed. Our goal was to clarify whether it takes the form of an abstract modality-general representation or of a concrete modality-specific representation. It is known that perceptual features such as balance, contour, symmetry, and complexity influence liking. Previous experiments examining liking for these attributes found that they elicit different subjective responses when mediated by visual (Corradi et al., 2019, 2020) and auditory (Clemente et al., 2021) objects. One possibility is that liking is the result of reward processes that operate on modality-specific cues—e.g., variety of colors in the visual domain vs. rhythmic syncopation in the musical domain—that contribute specifically to visual or auditory representations of balance, contour, symmetry, and complexity. Another possibility is that liking results from reward processes that operate on abstract modality-general representations—e.g., complexity—that emerge from cues that are common to visual and auditory balance, contour, symmetry, and complexity—e.g., number of elements or events.

In the present study, we directly compared responses to auditory and visual stimuli from the same cohort to ascertain whether aesthetic sensitivity is specific to each sensory modality or common across modalities. If the reward system operates on modality-general representations, then stimuli that share the same balance, contour, symmetry, and complexity profiles, regardless of whether they are visual or auditory, should be liked (or disliked) to a similar degree. If, on the contrary, the reward system operates on modality-specific representations, liking for visual balance, contour, symmetry, and complexity should be unrelated to liking for auditory balance, contour, symmetry, and complexity because of the substantially different nature (spatial vs. temporal) of the cues that drive liking in each modality. Noteworthy, the musical set used in this study purposely emulated the variation in the visual sets in the music domain, allowing us to investigate liking for balance, contour, symmetry, and complexity as comparably as possible across sensory modalities.

Table 3
Pairwise Correlations Between Individual Aesthetic Sensitivities Across Domains.

		Musical					
		BC1	CC1	CC2	SC1	KC1	KC2
Visual	VB	−0.089					
	VC		−0.422**	−0.116			
	VS				−0.152		
	VK					−0.215	0.118

Note. Spearman correlation coefficients of data from 48 participants regarding their liking for visual balance (VB), contour (VC), symmetry (VS), and complexity (VK); and musical balance (BC1), melodic contour (CC1), rhythmic contour (CC2), asymmetry (SC1), melodic complexity (KC1), and rhythmic complexity (KC2); ** $p < .01$.

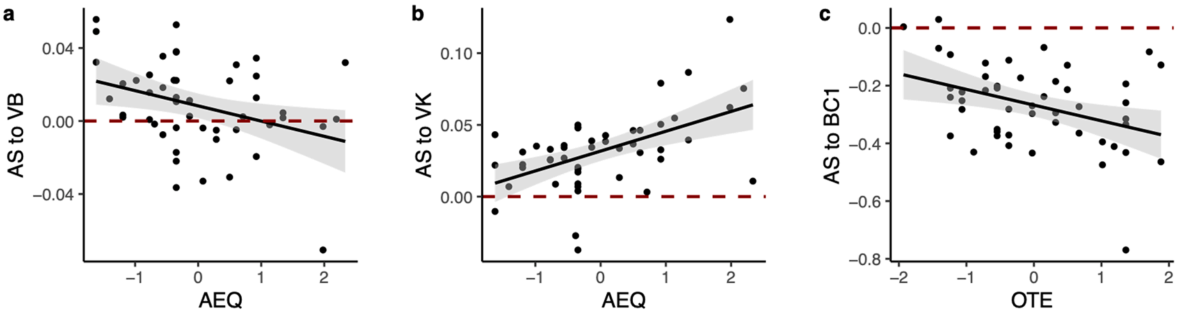

Fig. 5. Aesthetic sensitivities predicted by individual traits: (a) aesthetic sensitivity to visual balance (AS to VB) and (b) to visual complexity (AS to VK) predicted by interest and knowledge in visual art (AEQ), and (c) aesthetic sensitivity to musical balance (AS to BC1) predicted by openness to experience (OTE). Higher sensitivity values mean greater liking for higher visual balance and complexity, and lower musical balance, respectively. Gray ribbons correspond to 95% CI. Horizontal dashed lines mark the level of aesthetic indifference to each feature.

From a nomothetic perspective—i.e., at the group level—, our results support the notion of a general trend for people to prefer smooth (Bertamini et al., 2016; Palumbo, Ruta, & Bertamini, 2015), symmetric (Gartus & Leder, 2013), and complex designs (Nadal et al., 2010), and more balanced, asymmetric, and melodically complex melodies (Clemente et al., 2021; Marin, Lampatz, Wandl, & Leder, 2016; Marin & Leder, 2013). However, from an idiographic perspective—i.e., at the individual level—, the distributions of individual slopes demonstrate that people differ considerably in the degree and manner in which balance, contour, symmetry, and complexity influence their liking judgments. This discrepancy between nomothetic and idiographic approaches should caution against mistaking general tendencies for uniformity: overall trends in the features that influence liking coexist with substantial individual variations (Clemente et al., 2021; Corradi et al., 2019, 2020; Jacobsen, 2004; Jacobsen & Höfel, 2002).

In general, we found almost no evidence that aesthetic sensitivities correspond across the visual and auditory sensory modalities. For balance, symmetry, and complexity, the object features that our participants relied on to judge liking for visual designs were not equivalent to those they relied on to judge liking for melodies. The fact that one attribute influences someone's liking for music does not mean that the same attribute influences that person's liking for visual designs. Someone might, for instance, be aesthetically sensitive to visual complexity—e.g., complex designs are more liked than the simple ones—, but not to musical complexity—e.g., liking for melodies is not influenced by their complexity. This suggests that evaluative judgments entail the assessment by the reward circuit of modality-specific sensory attributes. Thus, evaluative judgments of visual designs and melodies are not based on abstract representations of balance, symmetry, and complexity, but on visual- and auditory-specific instantiations of such attributes: e.g., accumulation of all elements in a corner of the image in the case of visual balance, and concentration of all notes at the beginning or end in the case of musical balance; acute angles in the case of visual contour, and wide intervals in the case of musical contour; lack of correspondence in the elements at both halves of the image in the case of visual symmetry, and the absence of retrogradation from the middle point of a melody in the case of musical symmetry; many and varied constituting elements in the case of visual complexity, and highly unpredictable events in the case of musical complexity.

These results suggest that terms like *balance*, *complexity* or *symmetry* might be useful labels to describe and classify stimuli, but they seem to be inadequate and imprecise descriptions of the sort of attributes the sensory cortices convey to the reward system during evaluative judgments. This conclusion is in line with the results of a recent study that used magnetoencephalography to measure the amplitude of the magnetic N1 (N1m) component in response to auditory surprise in music experts and nonexperts: Quiroga-Martinez and colleagues (2020) found that the amplitude of the N1m increased with surprise. But they also found that it was pitch interval size, and not predictability, that was responsible for the modulation of the N1m component: when interval size was kept constant, surprise had no effect on N1m amplitude, but when surprise was kept constant, larger interval sized led to greater N1m amplitude. Quiroga-Martinez and colleagues (2020) concluded that N1m amplitude is explained better by the lower-level sensory processing of interval size than by probabilistic prediction, while the latter may be reflected by later components of the neural responses such as the P3am.

The only exception to the general pattern of results was a significant correlation between visual and melodic contour: participants who liked smooth images also tended to like melodically smooth melodies, and vice versa. We suggest that this correlation reflects similar negative affective effects of jagged musical contours and angular visual designs. *Smooth* music is deemed less arousing than more *energetic* or *intense* music (Zhang, Huang, Jiang, Gao, & Tian, 2010), reduces salivary cortisol secretion (Nomura, 2009), and is experienced as relaxing (Yu, Funk, Hu, & Feijs, 2018). Moreover, music around the world is characterized by melodic contours composed of small intervals (Mehr et al., 2019; Savage, Brown, Sakai, & Currie, 2015), probably reflecting energy constraints in production (Savage, Tierney, & Patel, 2017). Jagged melodies, therefore, are unlike familiar music in that they include mostly large intervals. Participants in our study, therefore, might have felt tension in response to their unusualness and high unpredictability (Clemente et al., 2021). Likewise, figures with angular contours are usually regarded as threatening or dangerous and induce greater activity in the amygdala than smooth counterparts (Bar & Neta, 2006, 2007; Gómez-Puerto, Munar, & Nadal, 2016). Thus, preference for contour in melodies and visual designs seems to reflect a lesser or greater degree of susceptibility to the affective responses to arousing, unusual, unpredictable, and potentially harmful visual or auditory stimuli. Further research is needed to ascertain whether this susceptibility is a specific expression of a broader suit of traits, such as affective reactivity, general anxiety, or aversion to broken patterns, known to influence different kinds of evaluative judgments (Gollwitzer & Clark, 2019; Landy & Piazza, 2019).

Finally, we modeled individual variability in aesthetic sensitivities as a function of art interest and knowledge, openness to experience, need for cognitive closure, and desire for aesthetics. Our results suggest that, overall, these factors explained minimal variation among participants in aesthetic sensitivity. There were three exceptions: On the one hand, openness to experience was only related to aesthetic sensitivity to musical balance, in line with Corradi et al. (2020), who found no effects of this trait on visual aesthetic sensitivities. One plausible explanation for this effect is that more balanced melodies may connote a stronger sense of development and continuity, in the sense of a more open musical discourse. On the other, visual art experience was related to aesthetic sensitivity to visual balance and complexity. The more participants were interested and knew about visual art, the more they liked complex and disliked balanced visual designs. This finding is in line with prior research showing that different forms of experience and expertise in visual art lead to a higher preference for complex and unbalanced visual designs (Eysenck, 1972; Eysenck & Castle, 1970). These results show no correspondence across the visual and auditory modalities in the way openness to experience and visual art interest and knowledge relate to aesthetic sensitivity. This lack of convergence also supports the notion that liking is influenced by concrete modality-specific representations of visual and auditory features and not by abstract amodal representations of those features.

This study is limited by the character of the stimuli employed. Further research is required to elucidate the extent to which these results hold with longer, polyphonic, non-Western, or atonal music, and with natural landscapes, paintings, or other sorts of visual stimuli. In addition, it is possible—and also desirable—to characterize and manipulate visual and musical balance, contour, symmetry, and complexity in other ways. Future studies using different criteria to define the same features we have taken into consideration could clarify the extent to which our results depend on the definitions that guided the design of the visual and musical stimuli we used.

In conclusion, our study shows that people vary substantially in the extent to which their evaluative judgments of visual designs and melodies depends on balance, contour, symmetry, and complexity. However, these differences in aesthetic sensitivity do not generally hold across modalities: the fact that complexity influences someone's liking for visual designs does not mean that complexity also influences their liking for melodies. This suggests that, in the process of hedonic valuation, the sort of attributes that are conveyed from sensory brain regions to the reward circuit correspond to concrete and modality-specific representations of visual and auditory features, rather than abstract modality-general representations of those features. The only exception was contour. We believe that this may reflect differences in people's general sensitivity to negative and arousing affect resulting from the potential threat, unusualness, and uncertainty inherent to jagged melodies and visual objects, and, conversely, positive and calm affect elicited by smooth music and figures.

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Appendix:. Adapted questionnaires

Adaptation from the Art Experience Questionnaire (AEQ)

Chatterjee, Widick, Sternschein, Smith II, and Bromberger (2010)

1 How interested are you in art? (0–6)

2 $_{\text{visual}}$. How often do you visit art museums or galleries?

2 $_{\text{auditory}}$. How often do you go to concerts?

3 How often do you look at art magazines or catalogs?

4 $_{\text{visual}}$. How often do you look at art on the Internet?

4 $_{\text{auditory}}$. How often do you listen to music?

5 $_{\text{visual}}$. How often do you speak about art with friends or family?

5 $_{\text{auditory}}$. How often do you speak about music with friends or family?

6 How many art history courses did you take during or after high school?

7 How many art creation courses did you take during and after high school?

8 $_{\text{visual}}$. How often do you create visual art?

8 $_{\text{auditory}}$. How often do you practice or make music?

9 $_{\text{visual}}$. How many hours on average do you spend creating visual art?

9 $_{\text{auditory}}$. How many hours on average do you spend making music?

Responses (2): Never / Once a year / Twice a year / Every three months / Once a month / Every second week / Weekly

Responses (3–5, 8): Never / Very rarely / Seldom / Few times / Sometimes / Often / Very often

Responses (6, 7, 9): 0–6 or more

NEO-FFI-R Openness to Experience Scale

McCrae and Costa (2004)

1. I like to concentrate on a dream or fantasy and, letting it grow and develop, explore all its possibilities.
2. I think it is interesting to learn and develop new hobbies.
3. The forms I find in art and nature arouse my curiosity.
4. I believe that allowing young people to hear people whose opinions are controversial can only confuse or mislead them.
5. Poetry has little or no effect on me.
6. I would have difficulty letting my thought wander without control or direction.
7. I seldom realize the humor or emotions that exist in each environment or moment.
8. I experience a lot of emotions or feelings.
9. Sometimes, when I read poetry, listen to music or contemplate a work of art, I feel a deep emotion or excitement.
10. I have little interest in thinking about the nature of the universe or the human condition.
11. I am very curious about intellectual issues.
12. I often enjoy playing with abstract theories or ideas.

Responses: Totally disagree / Disagree / Neutral / Agree / Totally agree

Adapted version of the Desire for Aesthetics Scale (DFAS)

Lundy, Schenkel, Akrie, and Walker (2010)

1 When I see beautiful things in daily life I rarely feel passionate about them.

2 One of the reasons I love traveling is seeing gorgeous scenery.

3 $_{\text{visual}}$. When watching a movie or series I enjoy noticing visual details (e.g., photography, framing, colors).

3 $_{\text{auditory}}$. When watching a movie or series I enjoy noticing musical details.

4 $_{\text{visual}}$. I enjoy spending time appreciating architecture.

4 $_{\text{auditory}}$. I enjoy spending time appreciating music.

5 I often find myself staring in awe at beautiful things.

6 I notice the details of brand logos.

7 I notice and care about design.

8 $_{\text{visual}}$. I notice and attend to the details in paintings, architecture, sculpture, and graphic work.

8 $_{\text{auditory}}$. I notice and attend to the details in music.

9 $_{\text{visual}}$. The details I notice in paintings, architecture, sculpture, and graphic work evoke emotions in me.

9 $_{\text{auditory}}$. The details I notice in music evoke emotions in me.

Responses: Totally disagree / Moderately disagree / Slightly disagree / Neutral / Slightly agree / Moderately agree / Totally agree

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Discussion

Discussion

Rationale for a New Conception of Aesthetic Sensitivity

Fechner (1860) was convinced that the lawful relations between the physical and the mental could be unveiled by examining the quantitative relations between stimulation and sensation. As sensation could not be measured directly, he devised indirect measures of the stimulus values required to generate sensation differences. Thus, differential sensitivity was central to psychophysics. Empirical aesthetics was born as applied psychophysics (Murphy, 1929). Specifically, Fechner (1876) devised empirical aesthetics to investigate sensory pleasure, as part of his more general hedonics (Clemente, in press, chapter III; Clemente, Pearce, & Nadal, 2021, chapter VIII; Nadal & Ureña, 2021).

Therefore, one of the foundational and primary goals of empirical aesthetics is to provide general explanations for how object features shape how people value them (Jacobsen, 2006; Pearce et al., 2016). Such explanations often rely on general perceptual, cognitive, and affective processes to account for regular and predictable responses to object features (Leder & Nadal, 2014; Pelowski, Markey, Lauring, & Leder, 2016). Over a century of research in empirical aesthetics suggests the existence of general preferences, some of which seem to transcend cultural (Che, Sun, Gallardo, & Nadal, 2018) and species boundaries (Munar, Gómez-Puerto, Call, & Nadal, 2015), and are modulated by other personal traits and the context (Cotter, Silvia, Bertamini, Palumbo, & Vartanian, 2017; Leder et al., 2019; Marin & Leder, 2018; Palumbo & Bertamini, 2016; Pecchinenda, Bertamini, Makin, & Ruta, 2014; Vartanian et al., 2019; Weichselbaum, Leder, & Ansorge, 2018). However, researchers noted early on that these general relations between stimulus features or configurations and aesthetic judgments coexisted with notable individual differences (e.g., Clark, Quackenbush, & Washburn, 1913; Martin, 1905, 1906). The way individual differences were treated and interpreted defined the idea and function of aesthetic sensitivity (Clemente, in press, chapter III).

The primary purpose of traditional notions of aesthetic sensitivity was to vindicate and promote a normative view of aesthetic appreciation whereby people were categorized as per their ability to correctly judge the beauty or artistic merit of objects (Che et al., 2018). Aesthetic sensitivity was the measure of such an ability. Indeed, the *determinist* view of aesthetic sensitivity was born to typecast people based on their innate abilities and to allocate them to careers suited to those abilities (Clemente, in press, chapter III; Corradi, Chuquichambi, Barrada, Clemente, & Nadal, 2020, chapter V). When applied to art, this urge for efficiently matching aptitude and occupation led to the development of multiple tests for artistic or aesthetic abilities (e.g., Meier, 1928; Thorndike, 1916). The results of these tests were presented as evidence for a single general aesthetic competence (Burt, 1933; Eysenck, 1940), presumed to be inherent to human nature (Eysenck, 1941a, 1941b, 1942, 1981) and measurable in all people regardless of culture (Eysenck & Iwawaki, 1971, 1975; Soueif & Eysenck, 1971), personality (Eysenck, 1983), and experience (Eysenck, 1940). The assumptions on which this conception relies, and how the construct is defined, are scientifically and historically conflicting (Clemente, in press, chapter III): Beauty is not an attribute of objects but of our experience of them, and there is no ability uniquely human, general, universal, innate, immutable, and unrelated to other traits and experience (Clemente, in press, chapter III; Clemente, Pearce, & Nadal, 2021; chapter VII; Corradi et al., 2020, chapter V). Besides, the instruments to measure it have faulty psychometric and conceptual validity (Chamorro-Premuzic & Furnham, 2004; Furnham & Chamorro-Premuzic, 2004; Myszkowski, Çelik, & Storme, 2018; Myszkowski, Storme, Zenasni, & Lubart, 2014; Payne, 1967).

The more humanist *educational* approach considered aesthetic sensitivity as an indicator of particular personality traits and artistic sophistication (Clemente, in press, chapter III). Aesthetic sensitivity turned into a skill to cultivate. There are, however, notable limitations to this notion also present in the determinist view: First, the methodological approach (Child and Iwao, 1968; Ford, Prothro, & Child, 1966; Iwao and Child, 1966; Iwao, Child, & García, 1969) is questionable in the sample sizes and composition (Che et al., 2018) used to claim the generality and artistic specificity of this ability (Child, 1965, 1981). Second, this notion focuses on artworks as if they were special and required a special human capability, which was disproved philosophically, psychologically, and neuroscientifically (Clemente, in press, chapter III; Nadal, 2020; Skov & Nadal, 2020a, 2020b, 2020c). Third, even if the emphasis regarding the nature of aesthetic sensitivity shifted from a biological determinism in the *determinist* view to the educability of an art-related capacity in the *educative* view, both conceptions relied on external norms set by some authority (Clemente, in press, chapter III). Therefore, the only contribution that traditional conceptions of aesthetic sensitivity can make to empirical aesthetics is to study how much people conform to, or deviate from, exogenous, imposed norms (Clemente, in press, chapter III).

But what would this show anyway? To say that someone has low aesthetic sensitivity, that is to say, is not good at discriminating beauty or has bad taste, makes sense only if it is the case that there exist objective beauty or standards of taste that people can notice and appreciate to varying degrees, and that scientists can measure in a meaningful way. But both of these premises are faulty. Perception is not a faithful and immediate reflection of reality. Everything we perceive, such as the colors we see and the speech sounds we hear, results from complex perceptual processes that rely heavily on context, past experience, and expectations. The belief that our perceptions are direct reflections of reality overlooks the intricate workings of perceptual systems that interact with memory and executive functions to make meaning of the continuous flurry of sensations we call experience. Beauty does not reside in the objects to be perceived with greater or lesser success. Beauty, taste, and aesthetic value are concepts that have developed in the particular context of Western thought to refer to the pleasure we get from perceiving (Skov & Nadal, 2020b). Thus, these words do not denote a quality of objects; they denote a quality of our experience of objects. If objective beauty or aesthetic value do not exist, there is nothing to measure, and no norm is required. If beauty and aesthetic value are, in fact, the pleasure of perception, what we do have is differences in the extent to which people find pleasure in perceiving.

As argued in the Introduction (chapter I), every scientific discipline and its constructs need to be re-defined and brought in line with established knowledge to be meaningful and useful (Clemente, in press, chapter III; Corradi et al., 2020, chapter V; Nadal, 2020). As for the discipline, Skov and Nadal (2020a) conceived aesthetics as the study of *sensory valuation*—i.e., the role of sensory information in the computation of hedonic value—, linking hedonics—i.e., the study of hedonic valuation itself—and neuroeconomics—i.e., the study of the integration of the computed hedonic values into decision-making and behavioral control. Hedonic values are responses to projections from sensory systems to distributed nuclei in the reward system, modulated by input from the interoceptive and executive systems—signaling homeostatic state and contextual information relevant to the valuation event (Bartra, McGuire, & Kable, 2013; Becker et al., 2019; Berridge & Kringelbach, 2015; Brown, Gao, Tisdelle, Eickhoff, & Liotti, 2011; Sescousse, Caldú, Segura, & Dreher, 2013). They are not uniquely human and can be considered affective states that motivate behavior according to individual and contextual factors (Skov, 2019; Skov & Nadal, 2019). People rely on sensory information to assign value to encountered or anticipated objects, situations, and events depending on their current state, goals, and expectations. Such a valuation capability enables deciding, comparing and choosing among alternatives, and prioritizing actions (Berridge & Kringelbach, 2013; Kringelbach, & Berridge, 2009; Levy & Glimcher, 2012). Therefore, sensory valuation is an essential aspect of cognition and vital for survival (Clemente, chapter IV; Skov, 2019, 2020; Skov & Nadal, 2020a).

Built in this integral renewal of the field, this doctoral research revises the construct of aesthetic sensitivity. Given its centrality for the notions of aesthetic experience and aesthetic appreciation (Clemente, in press, chapter III), this research may constitute a relevant contribution to the discipline's paradigm shift, not only adding to the historical, theoretical, methodological, and empirical grounds, but articulating concrete conceptual and empirical tools to investigate sensory valuation.

To that aim, first, a critical historical review was necessary to clarify the status of the issue. Consequently, I revised the notion of aesthetic sensitivity in the field throughout the history of empirical aesthetics (Clemente, in press, chapter III). This exercise revealed subtleties in the complex way the main traditional views on aesthetic sensitivity responded to particular programs, and that these constructs, immanent to the corresponding conceptions of aesthetic experience and appreciation, have misled the field more than contributed to understanding psychological processes. The fundamental conclusion was that the only way forward is to discard the traditional notions and measures, and to devise and probe empirically the validity and utility of a new conception in line with currently established scientific knowledge (Clemente, in press, chapter III).

Updated Definition

At the core of this thesis is the postulation of a new conception of aesthetic sensitivity. Approaching intuitive and common definitions of *sensitivity* (Clemente, in press, chapter III), we understand *sensitivity* as the individual responsiveness to variations in specific features—which is the very essence of psychophysics since Fechner (1860), and, hence, of empirical aesthetics in its origin (Fechner, 1876). Consequently, we defined *aesthetic sensitivity* as the extent to which a specific feature influences someone's aesthetic appreciation, and measured it as the individual slope in linear mixed-effects models. Although the idea was first implemented regarding liking for visual contour in Corradi et al.'s (2019) study, it was fully formulated and properly tested in Corradi et al. (2020, chapter V).

For the sake of accuracy and consistency with the sensory valuation framework and established and state-of-the-art research, I hereby posit several subtle tweaks in the terminology above while retaining the notion's essence: First, in Clemente (in press, chapter III), I suggested replacing *aesthetic* sensitivity by *hedonic* sensitivity to avoid the problematic term *aesthetic* and for consistency with the new approach to the field (Skov, 2019; 2020; Skov & Nadal, 2020a). Second, I advocate for substituting *aesthetic appreciation* in the definition by *sensory valuation*. As a result, the above definition would turn into: *Hedonic sensitivity* is the extent to which a specific feature influences someone's *sensory valuation*. One gain of this definition is that it encompasses any kind of hedonic value. However, the end product of sensory valuation in this research is a particular hedonic value, *liking*, which constitutes the focus of the studies conducted so far under this conception. Therefore, it stands to reason to formulate the construct in these studies as follows: *Hedonic sensitivity* is the extent to which a specific feature influences someone's *liking*. This definition's main advantages are that it is both more accurate regarding the neuroscientific framework, and broader in that it is not restricted to any *aesthetic* category. It is, indeed, close to original definitions of aesthetic sensitivity under this conception (Clemente, Pearce, & Nadal, 2021, chapter VIII; Corradi et al., 2020, chapter V), yet it avoids the inconsistent and problematic term *aesthetic*.

As noted in chapter IV, the terms *aesthetic appreciation* and *sensory valuation*, and *aesthetic sensitivity* and *hedonic sensitivity* have been used almost indistinctly throughout this doctoral research, only signaling emphasis on either continuity within the field (*aesthetic appreciation* and *aesthetic sensitivity*) or coherence with neuroscientific terminology (*sensory valuation* and *hedonic sensitivity*). Notwithstanding, now that our notion's historical roots have been clarified and discussed (Clemente, in press, chapter III), sticking with the *aesthetic* terminology seems incoherent, awkward, and debilitating. However, this by no means leaves room for the traditional notions to reclaim their identity and viability, as if an arbitrary category represented a meaningful entity (Clemente, in press, chapter III; Nadal, 2020). Quite the opposite, what I suggest is to shelve the traditional notions, measures (Corradi et al., 2020, chapter V), and name, as the dated, historical phenomenon that they constitute (Clemente, in press, chapter III).

Methodological Tools

To examine sensory valuation through this notion across sensory modalities, we chose four attributes that figure prominently in the literature on visual aesthetics and are susceptible to influence sensory valuation in the auditory modality as well: balance, contour, symmetry, and complexity. First, we used three well-known sets of b/w abstract visual designs, with their respective measures for each feature, to address aesthetic sensitivity in the visual modality (Corradi et al., 2020, chapter V).

Indeed, most research in empirical aesthetics has focused on the visual modality. However, music constitutes a fertile domain for studying general mechanisms of valuation (Mallik, Chandra, & Levitin, 2017; Salimpoor & Zatorre, 2013; Shepard, 1982; Trehub & Hannon, 2006) because it provides a rich and virtually unlimited set of materials (Cross, 2006; Rohrmeier, Zuidema, Wiggins, & Scharff, 2015; Trainor & Unrau, 2011), and it is highly valued among people (Dissanayake, 2008; Huron, 2003; Müllensiefen, Gingras, Musil, & Stewart, 2014; Nieminen, Istók, Brattico, Tervaniemi, & Huotilainen, 2011; Savage, Brown, Sakai, & Currie, 2015; Thoma, Ryf, Mohiyeddini, Ehlert, & Nater, 2012). We know that the valuation of music depends on many factors (Brattico & Pearce, 2013; Koelsch, Vuust, & Friston, 2018; Pereira et al., 2011; Van den Bosch, Salimpoor, & Zatorre, 2013) and involves the interaction of modality-specific and modality-general attributes (Marin, Lampatz, Wandl, & Leder, 2016; Marin & Leder, 2013; Purwins et al., 2008). However, besides the roles of familiarity, perceived complexity, and predictability (Brattico & Pearce, 2013; Güçlütürk, Jacobs, & Lier, 2016; Koelsch et al., 2018; Pereira et al., 2011; Van den Bosch et al., 2013), little is known about the extent to which the valuation of music and images rely on common attributes.

To investigate sensory valuation in music and across domains, we first needed to create adequate instruments. Therefore, inspired by the visual sets above, I composed the MUST, a set of musical motifs expressly devised for empirical studies combining experimental control and musical appeal (Clemente et al., 2020, chapter VII). I purposely emulated the variation in the visual sets that we used in Corradi et al. (2020) in the music domain, facilitating research on sensory valuation of stimuli varying in balance, contour, symmetry, and complexity as comparably as possible across sensory modalities. In Clemente et al. (2020, chapter VII), we assessed them behaviorally and computationally, deriving a battery of basic, conceptually irreducible, compact, and quantitative measures for the structural parameters manipulated in the stimulus design, and coded them as the MUST toolbox for MATLAB (MathWorks®). Noteworthy, the creation of a Python library has also been considered in collaboration with Yang—*pya*'s developer.

The results of the behavioral study suggested that participants understood the task in similar ways and judged the motifs using common criteria, that variations in each of the attributes were readily perceptible to non-musicians, and that participants' ratings concurred with the design of the stimuli. Therefore, we concluded that the four subsets are suitable for use in future studies that require presenting participants with short musical motifs varying in balance, contour, symmetry, or complexity. The 12 stimuli in each pole in each subset with the most extreme mean ratings and no strong disagreement among raters made up the abridged set (Clemente et al., 2020, chapter VII), which has been used in subsequent empirical approaches to aesthetic sensitivity (Clemente, Friberg, & Holzapfel, subm.; Clemente & Nadal, in prep.; Clemente, Pearce, & Nadal, 2021, chapter VIII; Clemente, Pearce, Skov, & Nadal, 2021, chapter IX).

In the computational study, a principal-component analysis revealed composite measures of musical balance, melodic and rhythmic contour, musical symmetry, and melodic and rhythmic complexity, which turned out to be excellent predictors of perceptual balance, contour, symmetry, and complexity, respectively, in linear mixed-effects models (Clemente et al., 2020, chapter VII). Our MUST_K model of perceived complexity predicted participants' ratings more accurately than FLAC compression (Coalson, 2008), the Expectancy-Violation model with four predictors (Eerola, 2016), and IDyOM's (Pearce, 2005, 2018) BOTH configuration, while the (less parsimonious) STM configuration was not significantly better. The results supported our approach's validity and suggested that musical complexity processing to some extent relies on isolable basic features such as those captured by the MUST_K model. Thus, this study not only contributed methodological tools but also shed light on music perception (Clemente et al., 2020, chapter VII; Sauvé & Pearce, 2019).

From these assessments, we concluded that the MUST set is sensitive to non-musicians' abilities to detect degrees of musical balance, contour, symmetry, and complexity, and that these were accurately captured by the MUST measures, because participants' judgments consistently matched the design of the motifs and were largely explained by our models. The coherence between design and assessments validated the MUST set and toolbox as reliable and useful resources for research in many fields, especially when the interest is audio–visual correspondence (Clemente et al., 2020, chapter VII). To facilitate their use as open sources for research, we made the MUST set and toolbox publicly available at Open Science Framework (https://osf.io/bfxz7/) and GitHub (https://github.com/compaes).

In the course of our studies on aesthetic sensitivity, we detected some unintentionally duplicated stimuli: Some symmetric stimuli in the Symmetry subset also appeared in the Complexity subset. Consequently, I created the new 1.1 version of the MUST—the old one being version 1.0—and made it available on the same site (https://osf.io/bfxz7/). In the MUST 1.1, new stimuli replaced the duplicated stimuli with similar values in the structural parameters of variation and control. This new set's validation is pending due to the COVID-19 pandemic and will be conducted as soon as in-site behavioral research is allowed and feasible at the University of the Balearic Islands.

Further developments include new assessments of the MUST stimuli and testing the MUST measures with longer, more varied, and naturalistic musical stimuli. In this regard, I have curated a new set of short musical excerpts from the Western repertoire varying in balance, contour, symmetry, or complexity as defined for the MUST. We are currently assessing the NatMUST stimuli behaviorally and computationally, and improving the MUST measures to make them more generalizable (Clemente, Kaplan, & Pearce, in prep.-b). Besides our research on aesthetic sensitivity, the MUST set and toolbox have been already used in Kurkor, Pearce, and Luft's (in prep.) study on musical creativity, Ulmeanu-Enea and Cova's (in prep.) study on the relationship between music and moral judgments, and Olszewska, Herman, Gaca, Drozdziel, and Marchewka's (in prep.) study on music-related brain plasticity with fMRI. Thus, the MUST's impact already transcends the field of empirical aesthetics.

Validity and Usefulness

With these materials, we first examined our new conception of aesthetic sensitivity in the visual (Corradi et al., 2020, chapter V) and auditory (Clemente, Pearce, & Nadal, 2021, chapter VIII) modalities separately by asking different cohorts of non-experts how much they liked stimuli varying in balance, contour, symmetry, or complexity. From a nomothetic perspective, the results supported the notion of a general trend for people to prefer curved, symmetric, and complex visual designs (Corradi et al., 2020, chapter V), and balanced, asymmetric, and melodically complex musical motifs (Clemente, Pearce, & Nadal, 2021, chapter VIII).

However, from an idiographic perspective, the results also showed that these group-level trends concealed a broad range of individual aesthetic sensitivities to structural properties. In other words, our new conception unveiled a wide individual variability in the degree to which liking depends on visual (Corradi et al., 2020, chapter V) and musical (Clemente, Pearce, & Nadal, 2021, chapter VIII) balance, contour, symmetry, and complexity. These individual sensitivities would have been masked by averaging across participants, despite the fact that they were very informative (Corradi et al., 2019; Güçlütürk et al., 2016, Güçlütürk & van Lier, 2019; Marin & Leder, 2018). Indeed, the variance explained by individual differences was considerable for each model, and removing the random slope within participants reduced the models' fit significantly (Clemente, Pearce, & Nadal, 2021, chapter VIII; Corradi et al., 2020, chapter V).

Aesthetic sensitivities to different features also differed within individuals, pointing to the existence of multiple sensitivities, as one may be differently sensitive to different features (Clemente, Pearce, & Nadal, 2021, chapter VIII; Corradi et al., 2020, chapter V). In short, the results showed a twofold variability: in the extent to which each individual considered each specific feature in sensory valuation. These would be neglected by traditional notions. Therefore, our conception restored the relevance of individual differences as informative of psychological processes. In fact, a further study (Clemente, Friberg, & Holzapfel, subm.) showed divergent general trends in spite of using the same stimuli and a similar paradigm, suggesting that overall effects of the features that affect hedonic valuation coexist with substantial individual variation and may be the source of many discrepant group-level findings in the literature. Moreover, it puts into question the relevance of general trends to understand sensory valuation (see also Clemente, in press, chapter III). The computation of hedonic value results from the interaction of sensory information and personal and contextual information, which are to some degree unique to the individual and the stimuli in a particular point in time. Our conception of aesthetic sensitivity informs about the way a particular sensory feature is used in this computation for a particular individual in a particular moment.

Remarkably, both visual (Corradi et al., 2020, chapter V) and musical (Clemente, Pearce, & Nadal, 2021, chapter VIII) individual aesthetic sensitivities seem to be stable in time. In other words, aesthetic sensitivity to a particular feature appears to be a consistent individual trait: The extent to which a particular feature affects a person's sensory valuation responds to a reliable pattern, at least within fortnight periods. Thus, the role of particular sensory features in sensory valuation seems to be more dependent on long-term factors such as experience than momentary states, at least under our experimental conditions. Nevertheless, our measure captured subtle temporal differences, providing a potential means to study learning and developmental processes in sensory valuation.

Visual aesthetic sensitivities to balance, contour, symmetry, and complexity appeared to be mostly unrelated (Clemente, Friberg, & Holzapfel, subm.; Corradi et al., 2020, chapter V), whereas most musical aesthetic sensitivities correlated significantly (Clemente, Friberg, & Holzapfel, subm.; Clemente, Pearce, & Nadal, 2021, chapter VIII). This led us to investigate whether the combinations of multiple individual sensitivities were finite and followed any pattern through a more sophisticated statistical technique: cluster analysis (Clemente, Friberg, & Holzapfel, subm.; Clemente, Pearce, & Nadal, 2021, chapter VIII). The results revealed that multiple individual sensitivities, at least in the music domain, tended to cluster into two distinct aesthetic sensitivity profiles, also stable in time (Clemente, Pearce, & Nadal, 2021, chapter VIII): Whereas participants belonging to profile 1 tended to like more unbalanced, jagged, asymmetric, and complex melodies, those with profile 2 showed the opposite preference. These findings suggest a plausible cognitive mechanism underlying the appreciation of the structural features manipulated in these studies: People tended to cluster together as per their preference for high (profile 1) or low (profile 2) informational predictability. This interpretation aligns with research on predictability in music (Cheung et al., 2019; Gold, Pearce, Mas-Herrero, Dagher, & Zatorre, 2019) and opens interesting questions about potential relationships between these profiles and information-related traits—e.g., *need for cognition* (Clemente, Friberg, & Holzapfel, subm.; Clemente, Kaplan, & Pearce, in prep.-a, Clemente & Pearce, in prep.)—, and whether this structure transcends sensory modalities. In this regard, we did not find any clustering of visual aesthetic sensitivities to structural features or across modalities (Clemente, Friberg, & Holzapfel, subm.). However, Güçlütürk and colleagues (2016) found a similar binary pattern of liking for visual complexity. Further research is required to clarify whether and to what extent informational features drive sensory valuation within and across sensory modalities.

The fact that comparable variability was unraveled using images (Corradi et al., 2020) or melodies (Clemente, Pearce, & Nadal, 2021) suggested an amodal computation of hedonic value. Consequently, to investigate whether evaluative judgments are mediated by abstractions into amodal representations, or hedonic value is computed directly from the sensory information, we examined visual and auditory aesthetic sensitivities to the same stimuli that we used in the visual (Corradi et al., 2020, chapter V) and musical (Clemente, Pearce, & Nadal, 2021, chapter VIII) studies but within people (Clemente, Pearce, Skov, & Nadal, 2021, chapter IX). Besides replicating general trends and an important variability in individual aesthetic sensitivities to each structural feature, the results suggested that liking for visual designs and musical motifs does not rely on abstract representations of balance, symmetry, and complexity, but on visual- and auditory-specific instantiations of such attributes. In sum, aesthetic sensitivities to balance, symmetry, and complexity seem to be modality-specific.

However, we found support for an amodal origin of contour preference, which we interpreted as reflecting differences in general sensitivity to negative and arousing affect resulting from the potential threat, unusualness, and uncertainty inherent to jagged melodies and sharp objects, and, conversely, positive and calm affect elicited by smooth music and curved figures (Clemente, Pearce, Skov, & Nadal, 2021, chapter IX). These differences might stem from biologically relevant experiences: On one hand, sharp objects are deemed more dangerous and induce greater activation in the amygdala (Bar & Neta, 2006, 2007; Gómez-Puerto, Munar, & Nadal, 2016). On the other, smooth melodic contours are prevalent around the world (Mehr et al., 2019; Savage et al., 2015), likely because they are easier to generate and process (Savage, Tierney, & Patel, 2017), and also entail physiological correlates of low arousal and positive valence (Nomura, 2009; Yu, Funk, Hu, & Feijs, 2018; Zhang, Huang, Jiang, Gao, & Tian, 2010). This interpretation concurs with hedonic values being affective states that motivate behavior (Skov, 2019).

On this matter, research shows that one may like what judges as negative and vice versa (e.g., Huron & Vuoskoski, 2020; Silvia, 2009). Thus, it stands to reason that sensory and affective valuation are separated processes. However, research also shows a general positive link between valence and liking (Leder, Tinio, & Bar, 2011; Palmer & Schloss, 2011), and preference for intermediate arousal levels (Berlyne, 1960). The consideration of hedonic values as affective states that motivate behavior (Skov, 2019) leads to wonder about how affective and sensory valuation relate: whether they are two aspects of the same valuation mechanism, or to what extent they are part of more general valuation processes, one influences the other—entailing temporal precedence and causality—, or one comprises the other. As the first step in this direction, Clemente, Friberg, and Holzapfel (subm.) inquired into the relationships between perceive-affect and hedonic judgments and between perceived-affect and hedonic sensitivities. In this study, we applied our notion and measure of hedonic sensitivity to perceived valence and perceived arousal of the same visual and musical stimuli used in Clemente, Pearce, Skov, and Nadal (2021, chapter IX). Among other findings, the results showed variability in hedonic sensitivities comparable to our previous studies, and variability in perceived-valence and perceived-arousal sensitivities comparable to those of hedonic sensitivities. Besides, the results confirmed modality- and feature-specific effects of the structural properties on both kinds of judgments and added support to a direct link between valence and liking (Leder et al., 2011; Palmer & Schloss, 2011), to the inverted-U model of arousal and liking (Berlyne, 1960), and the binary profile of musical (but not visual) hedonic sensitivities (Clemente, Pearce, & Nadal, 2021, chapter VIII). Further research is required to elucidate the degree to which affective and sensory valuation overlap as aspects of the same valuation mechanism and whether and how they are causally related. Besides these contributions to understanding sensory valuation, this study exemplifies a further use of our notion and measure: These are transferrable to other kinds of valuation and result similarly informative.

Clemente, Penacchio, Vila-Vidal, Pepperell, and Ruta's (in prep.) study constitutes another instance of transferrability. Here, we investigated the relationships between perceptual and hedonic judgments and sensitivities to visual contour. First, we created a new set of visual stimuli varying systematically and continuously in the number vertexes, the distance between internal and external vertexes, and the tension of the spline connecting adjacent vertexes. Then, we modeled perceptual and hedonic ratings on a continuous scale and 2AFC responses using the method of constant stimuli. The results suggest that shape and contour are different perceptual categories—shape mainly defined by distance—, and ask for caution in their empirical definition and manipulation. Also, context—here defined by the experimental paradigm—is crucial in determining perceptual and hedonic judgments of visual contour. Correlation analysis between perceptual and hedonic sensitivities suggests that perceptual and hedonic judgments tend to be independent when relying on vertexes and distance—which might imply a parallel processing of perceptual and hedonic judgments—, but to be associated when relying on tension, which seems to be the essential contour parameter across judgments and paradigms. Finally, we found no effects of time exposure, suggesting that both judgments take place at early-processing stages.

Worth noting is that Corradi et al. (2019) found that aesthetic sensitivity, at least to visual contour, transcends kinds of objects: People tended to be similarly sensitive to curvature regardless of whether the object was an abstract design or a real object. These results suggest that the sensory information influencing the computation of hedonic value is, at least in the case of contour, imbued with biologically relevant associations that downplay whether the object is real or abstract. Further research is needed to ascertain whether and what other sensitivities transcend kinds of objects. Apropos of visual contour, we are preparing a new study to assess the relationships between perceptual and hedonic sensitivities to different image projections of natural scenes, manipulating projection geometry on a continuous scale from rectilinear to spherical (Clemente, Burleigh, Pepperell, & Ruta, in prep.). Thus, we aim to extend Corradi et al.'s (2019) findings from object contours to scene projections.

We also inspected the relationships between sensitivities and other individual traits thought to affect appreciation in the literature. First, we modeled individual variability in aesthetic sensitivities as a function of intelligence, openness to experience, art interest and knowledge, need for cognitive closure, and desire for aesthetics. Overall, the effects of individual traits on aesthetic sensitivities were inconsistent across structural properties and sensory modalities, suggesting feature- and modality-specific influences (if any) on sensory valuation. (Clemente, Pearce, Skov, & Nadal, 2021, chapter IX; Corradi et al., 2020, chapter V). Remarkably, the results regarding visual aesthetic sensitivities differed between the visual study (Corradi et al., 2020, chapter V) and the one across domains (Clemente, Pearce, Skov, & Nadal, 2021, chapter IX), suggesting a tenuous association at a group level, likely mitigated by the low variability in expertise-related traits in these samples. Further studies with experts will clarify the existence and strength of relationships between aesthetic sensitivity and those traits.

Although inconsistent across studies as discussed above, suggesting a feeble (or even spurious) effect, the results suggest a positive relationship between visual art experience and preference for sharp-angled and asymmetric visual designs (Corradi et al., 2020, chapter V), and unbalanced and complex (Clemente, Pearce, Skov, & Nadal, 2021, chapter IX) visual configurations. These findings can be interpreted in terms of information-driven preferences, as higher expertise is thought to improve processing fluency, in turn facilitating liking for more informationally dense, unusual, or challenging objects (Chenier & Winkielman, 2009; Reber, 2012; Reber, Schwarz, & Winkielman, 2004; Schwarz, Jalbert, Noah, & Zhang, 2020).

The musical hedonic sensitivity profiles and the influence of domain-specific experience concur with the learning progress hypothesis (LP; Oudeyer, Gottlieb, & Lopes, 2016), which implies that the succession of progress niches through the development of expertise correlates with informational properties. According to the LP, learning progress generates intrinsic reward (Oudeyer & Kaplan, 2009; Schmidhuber, 1991) in humans and other animals (Kaplan & Oudeyer, 2007a, 2007b; Oudeyer & Smith, 2016). The LP posits that "the brain, seen as a predictive machine constantly trying to anticipate what will happen next, is intrinsically motivated to pursue activities in which predictions are improving, ie [sic], where uncertainty is decreasing and learning is actually happening" (Oudeyer et al., 2016, p. 265). Remarkably, the LP encompasses multiple views on motivation, novelty, and curiosity (Barto, Mirolli, & Balcasarre, 2013; Berlyne, 1960, 1965; Kidd & Hayden, 2015; Ryan & Deci, 2000), flow and optimal or manageable challenge (Csikszentmihalyi, 1990), information-based reward (Blanchard, Hayden, & Bromberg-Martin, 2015; Bromberg-Martin, Matsumoto, & Hirosaka, 2010), and related notions and traditions. Moreover, it is compatible with knowledge on the neurobiology of sensory valuation. This realization led us to investigate intrinsic motivation and hedonic sensitivity in free exploration and free play in music (Clemente, Kaplan, & Pearce, in prep.-a). The preliminary results using the MUST stimuli showed promising exploration and liking patterns driven by learning progress intrinsic motivation.

To investigate the impact of informational properties on hedonic sensitivity and their relations with the structural features addressed in these studies, we performed a *meta-analysis* of the combined data of our studies on hedonic sensitivity (Clemente & Pearce, in prep.). The preliminary results unveiled that hedonic sensitivity to information content moderated by entropy underlay liking for music across variation in structural properties, was slightly more stable than hedonic sensitivities to structural features, and defined the sensitivity profiles even more clearly than the structural features. However, when considering the MUST subsets separately, feature-specific sensitivities accounted for a greater proportion of the variance. These results suggest two partially overlapping parallel mechanisms in sensory valuation: one driven by informational properties transcending structural features, and the other driven by salient structural features—i.e., those whose relevance is enhanced by the presentation context, concretely in this case, the source of variation in each subset.

Interestingly, Clemente, Friberg, and Holzapfel (subm.) found that the trait *need for cognition* (Cacioppo & Petty, 1982) predicted hedonic sensitivities in the same direction as the hedonic sensitivity profiles: People high in this trait tended to more unbalanced, jagged, and melodically complex music, and more asymmetric images. *Need for cognition* is associated with general intelligence, fluid intelligence, and crystallized intelligence, but not working memory (Hill et al., 2013). Thus, the role of working memory and these kinds of intelligence in sensory valuation calls for investigation. This naturally poses the question of whether information-driven but not feature-specific mechanisms—the two parallel processes of sensory valuation suggested by our meta-analysis—are moderated by *need for cognition*. Notwithstanding, this trait predicted hedonic sensitivity to information content *and* hedonic sensitivities to structural features (Clemente & Pearce, in prep.). These results, together with the hedonic sensitivity profiles and the shared variance explained by structural and informational features, suggest that they overlap to some extent. Further research, particularly inquiring into the role of working memory in sensory valuation, may help elucidate the existence of the hypothesized mechanisms and disentangle the contributions of informational and structural features to sensory valuation.

Most sensory experiences are multisensory experiences, such as appreciating a dance performance, an opera, a play in the theatre, or a movie. These experiences also share a key characteristic: They unfold in time. Thus, any serious investigation of sensory valuation should account for multisensory aspects, such as cross-modal effects, and consider the temporal dimension of both auditory and visual sequences. This is precisely the rationale behind Clemente, Board, Pearce, and Orgs' (in prep.) study, in which we developed a set of non-representational audiovisual displays that varied systematically in auditory (number of sounds) and visual (number of moving lines) complexity. Liking increased linearly with audiovisual complexity and was predicted by a linear combination of their unimodal preferences. Additionally, our findings suggest a form of auditory aesthetic capture: Disliking the visual component can be offset by a strong preference for the auditory component, but overly disliking auditory components entails that the audiovisual displays are never liked. Besides, informational properties predicted hedonic ratings of visual sequences better than the structural properties, but the latter were better predictors of liking for auditory and audiovisual sequences, likely due to the influence of pitch variety and audiovisual congruence, which also affected liking positively. Interestingly, the results point to modality-specific effects of structural complexity and a modality-general influence of information content, although both complexity kinds overlap to a great extent. We also found a binary profile of hedonic sensitivities to complexity irrespective of whether structural or informational, visual or auditory, or in unisensory (visual or auditory sequences) or bisensory (audiovisual sequences) stimuli. Finally, musical sophistication modulated aesthetic sensitivity to audiovisual congruence, positively moderated by age: The higher in this trait and the elder, the more people liked congruence in auditory and visual complexities in audiovisual displays.

In the studies integrating this doctoral dissertation and the ongoing derived research, we observe a fascinating tension between specific and general influences and between nomothetic and idiographic considerations of sensory valuation. On the one hand, salient stimulus features explain a relevant portion of the variability in liking judgments. Their effects tend to be modality-specific and relate to other traits in a modality-specific fashion (Clemente, Pearce, & Nadal, 2021, chapter VIII; Clemente, Pearce, Skov, & Nadal, 2021, chapter IX; Corradi et al., 2020, chapter V). On the other, humans appear to show a modality-general preference for contour (Clemente, Pearce, Skov, & Nadal, 2021, chapter IX), and information processing is contemplated as a plausible underlying factor accounting for a considerable variance of liking judgments across features and defining aesthetic sensitivity profiles at least in the auditory modality (Clemente, Pearce, & Nadal, 2021, chapter VIII).

In summary, aesthetic or hedonic sensitivity conceived as individual responsiveness to variations in stimulus features turned out to be a fruitful research tool to investigate sensory valuation in the musical and visual domains. Apart from validating our conception of aesthetic sensitivity in both sensory modalities, these studies contributed to shed light on the nature of sensory valuation. The studies included in this doctoral research revealed that aesthetic sensitivity appears to be a multidimensional and stable construct—entailing wide variation in the extent to which particular structural features affect hedonic valuation between and within people—, and tends to be modality- and feature-specific, although they also unveiled an amodal origin for contour and musical aesthetic sensitivity profiles. Our notion and measure and the findings uncovered through it pose new questions and cues to investigate valuation processes further while providing an advantageous and reliable platform for a sophisticated investigation of sensory valuation.

Prospective and Upcoming Research

From the discussion above, it seems evident that our notion and measure have been proved valid and useful to investigate sensory valuation. Furthermore, their impact transcends the research included in this dissertation, fostering stimulating lines of investigation—examples of which are the ongoing studies mentioned in the previous section. In this section, I proffer several ways in which future research on hedonic sensitivity may proceed in terms of further applications and improvements of our notion and measure.

Further applications

To understand sensory valuation, it is crucial to examine the factors that may modulate hedonic sensitivity, such as expertise, exposure, or context. So far, our studies have only included non-experts to allow for the generalization of our findings to the general population. However, examining the effects of expertise on hedonic sensitivity is essential to understand how it develops, and how psychological and neural correlates of expertise influence it. Also, exposure to objects with particular feature levels may affect the hedonic sensitivity to that feature. Likewise, different contexts and tasks may also exert priming effects or somehow impose constraints on hedonic sensitivities (e.g., Clemente, Penacchio, et al., in prep.). Thus, experimental paradigms in which these factors are manipulated, perhaps in combination with neuroimaging techniques, are essential to advance our knowledge of sensory valuation.

Similarly, exploration and learning tasks like those in Clemente, Kaplan, and Pearce's (in prep.-a) study are needed to test the LP and its role in sensory valuation. Noteworthy, the object of learning may be varied. For instance, in a further iteration of our paradigm, we used cultural (or style) distance between musical corpora (e.g., Chinese–Western, Irish–German). Notwithstanding, other aspects are also susceptible to learning and may affect hedonic valuation. Besides, a similar investigation is also required in other sensory modalities.

As noted in the previous section, sensory valuation may involve parallel processes, each concerning a particular aspect of the sensory information: e.g., affective–hedonic (Clemente, Friberg, & Holzapfel, subm.), perceptual–evaluative (Clemente, Penacchio, et al., in prep.), structural–informational (Clemente & Pearce, in prep.). Inquiring into the psychological and neural underpinnings of these sensitivities is crucial to understand how they relate and, thus, offer a more detailed picture of sensory valuation and other cognitive processes. Furthermore, the role of different kinds of intelligence and memory may help elucidate the interplay between sensory information and personal and contextual factors in sensory valuation.

Neurobiological explanations, e.g., in terms of connectivity between sensory-processing brain areas and the reward circuit, might clarify the origin of differential hedonic sensitivity. Research shows that individual capacity to experience musical pleasure correlates with differences in connectivity between the auditory cortex and the reward circuit (Loui et al., 2017; Martínez-Molina, Mas-Herrero, Rodríguez-Fornells, Zatorre, & Marco-Pallarés, 2016). In the extreme case of specific musical anhedonia (SMA), reduced white matter connectivity between auditory brain regions and the ventral striatum seems responsible for the inability to experience pleasure from music (Sachs, Ellis, Schlaug, & Loui, 2016). However, the processing of structural and informational musical features in people with SMA seems to be intact. Then, it remains the question of whether such deficient connectivity is equally detrimental to hedonic sensitivity to structural and informational features, or to what extent pleasure can be derived from—and thus, hedonic valuation can rely on—information-driven reward, overcoming such poor connectivity. Also, the impact of connectivity between visual areas and the reward system upon hedonic sensitivity to visual objects calls for examination.

Genetic factors may contribute to the manifestation of different hedonic sensitivities, plausibly interacting with experience and learning. For instance, a predisposition to affective sensitivity might enhance reactivity to sensory information. Such a tendency might be at the basis of an amodal hedonic sensitivity to contour, with people high in affective sensitivity avoiding threatening or unpredictable stimuli and preferring smooth and predictable ones (Clemente, Pearce, Skov, & Nadal, 2021, chapter IX). Experience with sharp and unpredictable objects may, in turn, offset such a tendency (Clemente, Pearce, & Nadal, 2021, chapter VIII; Corradi et al., 2020, chapter V), and learning may even reverse it. Disentangling genetic and environmental influences on sensory valuation becomes imperative. In other words, investigating the role of biological–genetic and cultural–environmental factors in sensory valuation is crucial to understand the computation of hedonic value.

Also, inquiring into the role of personality and temperamental factors appears to be essential to understand the origin of hedonic sensitivity profiles, the amodal preference for contour, and the role of information processing and psychological traits in interaction with sensory information in sensory valuation. For instance, anxiety and apprehension may explain a general preference for predictable stimuli. Recent research in this regard points to a positive association between these traits and hedonic sensitivity to visual symmetry, so that anxious and apprehensive individuals seem to be more sensitive to disgust and prefer more symmetric patterns (Dorado, Skov, Rosselló, & Nadal, in press).

Importantly, one may apply our conception of hedonic sensitivity to other constructs like beauty, like we did with judgments of perceived affect (Clemente, Friberg, & Holzapfel, subm.). In such an approach, Che et al. (in press) compared the impact of working-memory overload on hedonic sensitivity and beauty sensitivity. Interestingly, they found that beauty judgments involved higher working-memory demands, and thus, suffered more than liking judgments from the concurrence of tasks limiting working-memory capacity. This suggests that liking judgments are more direct and involve less cognitive resources than assessing beauty, for which more memory resources—likely involving templates—are engaged.

Noteworthy, hedonic sensitivity is not bounded to the features addressed in this doctoral research. As it happens, Clemente and Pearce (in prep.) applied it to information content and entropy, and compared hedonic sensitivities to these information-theoretic features with hedonic sensitivities to the structural features addressed in this doctoral research. Another example is Clemente, Burleigh, et al.'s (in prep.) approach, extending hedonic sensitivities to visual contour to geometric projections. But further applications are feasible and desirable: e.g., using relevant domain-specific features such as tonal strength or visual contrast.

Research on sensory valuation and hedonic or aesthetic sensitivity has mainly focused on the visual and auditory modalities. However, our notion and measure can and should also be applied to other sensory modalities and domains. After all, we assign value to all kinds of objects irrespective of their nature. Especially appealing is extending our conception to haptic stimuli and elucidating, for example, the existence of comparable haptic hedonic sensitivities, whether the visual–musical preference for contour also applies to tactile stimuli, whether there are any haptic hedonic sensitivity profiles, or the factors affecting tactile hedonic sensitivity and their relationships with other hedonic sensitivities. One advantage of the structural features we chose is that they are potentially multi-modal to some degree, in the sense that configurations and objects with different degrees of balance, contour–curvature, symmetry, and complexity may also be appraised through touch. Smell and taste constitute another promising field of investigation in terms of hedonic sensitivity. However, some of the attributes focus of this doctoral research would be only considered metaphorically: For instance, one may well appraise the complexity of a given taste or smell, whereas assessing its symmetry would require abstract associations hardly related to actual sensory features.

Particularly fascinating to me is the investigation of temporal processes and dynamic stimuli in sensory valuation. Clemente, Board, et al.'s (in prep.) study is the first step in that direction. Further research might combine behavioral, neuroimaging, computational, and AI approaches, and thus, be of interest to a broad range of scientific fields, with applications to, e.g., robotics or medicine. Indeed, shedding light on sensory valuation may inform AI models or therapeutical techniques, for example, apart from advancing the understanding of how the mind/brain works.

Improvements

Sensory valuation involves valuing objects according to sensory information and personal and contextual factors. So far, and like in most literature in empirical aesthetics, we have focused on liking. Nevertheless, other value signals are also computed that reflect distinct phases of motivated-behavior regulation (Clemente, chapter IV; Skov, 2019). Among these, *wanting* values are of particular interest. One may want but not like something, and vice versa. Thus, applying our conception to wanting and developing an analogous notion and measure of *wanting sensitivity* would also contribute to the investigation of sensory valuation. Of special relevance is clarifying how these two sensitivities relate.

Also in favor of our approach's generalizability is to rename the notion as suggested in Clemente (in press, chapter III). I now suggest a step further: to include *wanting sensitivity* and *hedonic sensitivity*—earlier aesthetic sensitivity— in the study of sensory valuation, accounting for the different phases and value mechanisms of motivated-behavior regulation as a function of sensory information. Accordingly, *wanting sensitivity* is defined as the extent to which a particular feature influences someone's *wanting*, and *hedonic sensitivity* is defined as the extent to which a specific feature influences someone's *liking*.

Up until now, we have addressed univocal judgments of short or static objects. However, actual interaction with sensory stimuli is not restricted to four seconds, and, especially for objects or events that unfold over time, valuation is a continuous process. To overcome this limitation and make our conception suitable to any valuation event, thus affording the research with which I concluded the previous section, we must account for temporal processes and develop a continuous measure. I propose that such a measure might be a fine-grained assessment of the variation of hedonic value over time, formulated as the second derivative of liking judgments throughout the encounter and evaluation of the stimulus. An interesting question is whether averaged or aggregated over the duration of the interaction with the stimulus might approximate the current overall linear assessment. We are currently testing this approach in music (Clemente & Pearce, in prep.), but validations in other domains such as dance are desirable.

So far, only linear relationships can be captured by our measure. However, theories like Berlyne's (1960) point to quadratic relationships between, e.g., complexity and liking. Consequently, we also explore a nonlinear measure in Clemente and Pearce (in prep.). It involves at least three indices—for quadratic functions—determined by the three coefficients of the function $f(x) = ax^2 + bx + c$: *amplitude*/*slope* (a), *vertex*/*apex* (x, h), and *intercept* (c). These are computed as follows:

- The coefficient a controls the degree of curvature of the graph: A larger magnitude of a gives the graph a more closed appearance. If $a > 0$, the parabola opens upwards, whereas if $a < 0$, the parabola opens downwards.
- The three coefficients determine the location of the parabola's symmetry axis at ($-b/2a$, $c-b^2/4a$).
- The coefficient c defines the height of the parabola, where it intercepts the y-axis.
- The vertex is the parabola's turning point.

How these measures relate and how they vary between participants will inform about the individual sensitivities with more detail than our current measure. For example, a quadratic function may also have a linear component, or both arms of the parabola may cancel each other. In the former scenario, only the linear component would be captured by the current measure. In the latter, the person would be considered insensitive. In both cases, the actual preference for particular degrees of the feature would be concealed by the linear measure.

Summary

We have put forward a new conception and measure of aesthetic or hedonic sensitivity in line with current established knowledge. Our notion and measure have proven valid and useful to investigate sensory valuation. An increasing number of studies using it have contributed to understanding the computation of hedonic value. Our findings advance the understanding of sensory valuation and pave the way for further research. Besides, our measure is transferrable to other constructs, sensory modalities, and object features, exponentially increasing its potential uses. Therefore, the impact of our conception is not restricted to the studies included in this dissertation, even if these are certainly important contributions. Beyond the present findings, our notion and measure, as well as the MUST set and toolbox, constitute valuable tools in this and related fields: They fulfill the purpose for which they were devised and their usefulness even transcends the field of empirical aesthetics.

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XI

Conclusion

Conclusion

Sensory valuation is a fundamental neurobiological process, an essential aspect of cognition, and vital for survival. A comprehensive understanding of sensory valuation requires accounting for individual differences (Clemente, chapter IV). The way these have been considered in empirical aesthetics gave rise to different conceptions of aesthetic experience, with *taste* or *aesthetic sensitivity* as its main instrument. Thus, the idea of aesthetic sensitivity was born central in the field (Clemente, in press, chapter III).

A critical historical investigation of the origin and development of the polymorphic idea of aesthetic sensitivity (Clemente, in press, chapter III) unraveled structural incongruences in the field and the prevalence of scientifically unsupported notions—heavily loaded and exerting a pervasive socio-political impact. After arguing thorough and compelling reasons to discard traditional notions and measures of aesthetic sensitivity, we put forward a new conception of aesthetic sensitivity (Clemente, in press, chapter III; Clemente, Pearce, & Nadal, 2021, chapter VIII; Corradi, Chuquichambi, Barrada, Clemente, & Nadal, 2020, chapter V; Nadal, Corradi, Barrada, Clemente, & Chuquichambi, 2020, chapter VI)—later, *hedonic sensitivity* (Clemente, chapter X)—, defined as the extent to which a particular feature influences the hedonic valuation—specifically, liking in this research—of a sensory object (Clemente, chapter X).

Subsequently, we developed the MUST set and toolbox (Clemente et al., 2020, chapter VII) to test the new notion and measure not only in the visual domain (Corradi et al., 2020, chapter V) but also in the musical one (Clemente, Pearce, & Nadal, 2021, chapter VIII) and across domains (Clemente, Pearce, Skov, & Nadal, 2021, chapter IX).

In a nutshell, the results of these empirical studies revealed that individual visual and musical aesthetic sensitivities to balance, contour, symmetry, and complexity vary widely between individuals, are multiple, stable in time, barely related with other individual traits, mainly feature- and modality-specific, and tend to cluster into musical aesthetic sensitivity profiles (Clemente, in press, chapter III; Clemente, Pearce, & Nadal, 2021, chapter VIII; Clemente, Pearce, Skov, & Nadal, chapter IX; Corradi et al., 2020, chapter V). The implications for understanding sensory valuation are relevant and direct, because aesthetic sensitivity refers to the role of a given feature in the sensory valuation of an object for a particular individual. In other words, it is a measure of individual variability in the extent to which hedonic value relies on a particular feature (Clemente, chapter IV, chapter X).

In conclusion, this doctoral thesis constitutes a thorough revision of the construct of aesthetic sensitivity that contributes to the integral renewal of the field proposed by Skov and Nadal (2020a). Our primary and overarching goal was to advance the scientific investigation of sensory valuation through a new conception of aesthetic sensitivity. To achieve it, this research articulated around specific historical (Clemente, in press, chapter III), theoretical (Clemente, in press, chapter III; Clemente, Pearce, & Nadal, 2021, chapter VIII; Corradi et al., 2020, chapter V; Nadal et al., 2020, chapter VI), methodological (Clemente et al., 2020, chapter VII), and empirical objectives (Clemente, Pearce, & Nadal, 2021, chapter VIII;

Clemente, Pearce, Skov, & Nadal, 2021, chapter IX; Corradi et al., 2020, chapter V) materialized into scientific publications. Beyond the aforementioned relevant findings, this research's impact already ramifies into ongoing and future empirical studies, even transcending the field scope (Clemente, chapter X).

Therefore, the value of this doctoral research is manifold, as it entails profound epistemological considerations, provides new tools and empirical evidence, poses new research questions, and paves the way for further scientific inquiry into sensory valuation by establishing an advantageous platform for scientific research.

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