Explaining the *Curvature Effect*:

Perceptual and Hedonic Evaluations of Visual Contour

Ana Clemente, Olivier Penacchio, Manel Vila-Vidal, Robert Pepperell, and Nicole Ruta

Author Note

Ana Clemente, Human Evolution and Cognition Research Group (EvoCog), University of the Balearic Islands, Department of Cognition, Development and Educational Psychology, Institute of Neurosciences, University of Barcelona, and Cognition and Brain Plasticity Unit, Bellvitge Biomedical Research Institute, Spain; Olivier Penacchio, School of Psychology and Neuroscience, University of St. Andrews, UK, and Computer Vision Center, Computer Science Department, Universitat Autònoma de Barcelona, Spain; Manel Vila-Vidal, Center for Brain and Cognition, Departament de Tecnologies de la Informació i la Comunicació, Universitat Pompeu Fabra, Barcelona, Spain; Robert Pepperell, FovoLab, Cardiff Metropolitan University, UK; Nicole Ruta, School of Divinity, University of St. Andrews, UK, and Laboratory of Experimental Psychology, Department of Brain and Cognition, KU Leuven, Belgium

The project leading to these results has received funding from “La Caixa” Foundation (ID 100010434) under agreement LCF/BQ/ES17/11600021 awarded to AC, from “La Caixa” Foundation (ID 100010434) under agreement LCF/BQ/DE17/11600022 awarded to MV, and OP was partially funded by a Leverhulme grant (RPG-2019-96) to Professor Julie M. Harris and a Research Incentive Grant from the Carnegie Trust (RIG009298).

AC led the project and NR supervised it. AC and NR conceptualized and formulated the overarching research ideas, goals and aims; designed and conducted the experiments and collected the data. AC and MVV created the stimuli and computational measures. MVV developed the open-access tool. AC, OP and NR analyzed the data. RP and NR acquired the financial support for the experiments. AC drafted the manuscript. AC, OP, MVV, RP and NR revised the manuscript.

The authors declare that there is no conflict of interest.

Corresponding author: Ana Clemente, Human Evolution and Cognition Research Group (EvoCog), University of the Balearic Islands, Crta Valldemossa km 7.5 Palma de Mallorca 07122 Spain, ana.c.magan@gmail.com.

Abstract

Preference for curvature, the *curvature effect*, seems to transcend cultures, species and stimulus kinds. However, its nature and psychological mechanisms remain obscure because studies often overlook the complexity of contour characterisation and disregard personal and contextual factors. To investigate the *curvature effect*, we propose a continuous and multidimensional manipulation and contrasting experimental conditions examined at the group and individual levels that unveil a complex picture, not reducible to monotonous relationships: Perceptual and hedonic evaluations relied on multiple geometric features defining contour and shape. These features were specifically weighted to characterise each construct, depending on the individual and contingent on whether evaluating perceptually or hedonically. Crucially, the *curvature effect* was not robust to preference with respect to the median and continuous manipulations of contour for varying shapes. As curved contours are more easily perceived and processed than polygons, we hypothesised that perceived contour might explain liking for a figure beyond the effect of geometric features, finding that this association was subordinated to shape categorisations. Finally, domain-specific, personality and cognitive-preference traits moderated how people used each geometric feature in their perceptual and hedonic evaluations. We conclude that research on perception and appreciation of contour and shape should factor in their complexity and defining features. Additionally, embracing individual sensitivities opens potential avenues to advance the understanding of psychological phenomena. In summary, our approach unpacks a complex picture of contour preference that prompts critical reflections on past research and advice for future research, and it is applicable to other psychological constructs.

Keywords: contour; curvature effect; perception; preference; sensitivity

Explaining the *Curvature Effect*:

Perceptual and Hedonic Evaluations of Visual Contour

Perception and appreciation (i.e., hedonic evaluation) of sensory objects are fundamental aspects of cognition. On the one hand, sensory cues allow us to determine objects' categories, properties, regularities and relationships to make sense of the world (Wagemans, 2015). On the other hand, we rely on sensory information to assign hedonic value to objects, situations and events we encounter or anticipate, depending on our current state, goals and expectations (Skov, 2019, 2020; Skov & Nadal, 2021). Likewise perception, appreciation is crucial for survival (Skov, 2019), as this ability to judge as desirable or avoidable, liked or disliked, beneficial or damaging enables comparing, deciding and prioritizing actions (Pessiglione & Lebreton, 2015; Rangel, Camerer & Montague, 2008). It is reasonable to assume that perception and appreciation of sensory objects are interrelated processes. However, whereas research has revealed how appreciation biases perception (Skov, 2019), how perception affects appreciation remains unclear.

Humans greatly rely on vision as a primary sense for perceiving and evaluating objects and events (Hutmacher, 2019). Contour is a prominent factor driving perceptual (Wolfe, Yee & Friedman-Hill, 1992; Wagemans, 2015, 2018; Bertamini & Wagemans, 2013; De Winter & Wagemans, 2008) and hedonic evaluations of visual objects in humans (Gómez-Puerto, Munar & Nadal, 2016), great apes (chimpanzees and gorillas in Munar, Gómez-Puerto, Call & Nadal, 2015), macaques (Yetter et al., 2021) and even chicken (Fantz, 1961). Contour is usually defined in terms of regions of convex and concave curviness along the object's profile (Schmidtmann, Jennings & Kingdom, 2015). Convexity provides critical information for figure–ground separation (Arnheim, 1954; Biederman, 1987; Bertamini, 2001, 2008; Bertamini & Wagemans, 2013; Kanizsa, 1976; Koffka, 1935; Mach, 1959), visual search tasks (Treisman & Gelade, 1980; Wolfe et al., 1992) and motion processing (Caplovitz & Tse, 2007; Tse & Caplovitz, 2006). Recently, Bertamini, Palumbo and Redies (2019) showed that smooth contours are detected faster than angular contours, and Yue, Robert and Ungerleider (2020) provided empirical evidence for a specialized cortical network for curvature processing in humans. Aligned with these findings, developments in image analysis and computational models of the early visual cortex suggest that more curved contours cause lower visual discomfort and hyper-excitability in V1 than their angular counterparts (Le et al., 2017; Penacchio & Wilkins, 2015).

Over a century of research in empirical aesthetics consistently indicates that people generally prefer curved to angular contours (Bertamini, Palumbo, Gheorghes & Galatsidas, 2016; Corradi, Chuquichambi, Barrada, Clemente & Nadal, 2020; Hevner, 1935; Lundholm, 1921; Palumbo, Ruta & Bertamini, 2015). This well-established phenomenon is known as the *curvature effect* (Corradi & Munar, 2020; Palumbo & Bertamini, 2016). It is present in early developmental stages (Jadva, Hines & Golombok, 2010; Ruff & Birch, 1974) and transcends cultures (Che, Sun, Gallardo & Nadal, 2018; Gómez-Puerto et al., 2018), species (Fantz, 1961; Munar et al., 2015; Yetter et al., 2021) and stimulus kinds (Corradi et al., 2019; Vartanian et al., 2019; Ruta, Mastandrea, Penacchio, Lamaddalena & Bove, 2019). However, some issues in the empirical aesthetics literature hamper our understanding of the *curvature effect* and its underlying psychological mechanisms. We review them in the remainder of this section.

First, visual contour seems to be poorly characterised and operationalised. In particular, most studies on visual contour preference have overlooked continuous variations in the features characterising contour or do not control structural parameters systematically (e.g., Bar & Neta, 2006, 2007; Bertamini et al., 2016; Coburn et al., 2020). Namely, most studies treat contour as a binary dimension—with extensions to mixed contours based on such dichotomy (e.g., Leder & Carbon, 2005; Bar & Neta, 2006; Ruta et al., 2019; Ruta et al., 2021). However, *curved* is just one extreme of the continuous theoretical construct *contour*, the other extreme being *angular*. Moreover, contour has been studied using stimuli that manipulated more than one geometric feature at a time (e.g., the number of vertexes and the distance between vertexes in Bertamini et al., 2016), while defining curvature in terms of curved vs angular versions of the same basic shape. Therefore, we question whether people would prefer curved contours even when they are manipulated continuously while controlling each geometric dimension separately.

Second, most studies have focused on group-level effects (e.g., Bar & Neta, 2006; Bertamini et al., 2016; Palumbo et al., 2015), which conceals considerable individual differences that are key to understanding the psychological mechanisms driving preferences (Clemente, 2022; Clemente, Pearce, Skov & Nadal, 2021; Corradi et al., 2020). Thus, it seems reasonable to ask whether the *curvature effect* is genuine in the sense that it reflects a meaningful psychological phenomenon operating at the individual level.

Third, the impact of context on perceptual and hedonic evaluations is often overlooked, even if it is known to affect perceptual (Powell, Meredith, McMillin & Freeman, 2016; Skewes, Jegindø & Gebauer, 2015; Zaidel, Goin-Kochel & Angelaki, 2015) and hedonic evaluations (Cotter, Silvia, Bertamini, Palumbo & Vartanian, 2017; Gollwitzer & Clark, 2019; Landy & Piazza, 2019; Palumbo & Bertamini, 2016; Vartanian et al., 2019). If genuine, it is essential to uncover the individual and contextual factors associated with the *curvature effect* and its underlying mechanisms.

Unpacking the *curvature effect*

This research's primary and overarching aim was to unpack the *curvature effect*; that is, to advance the understanding of its underlying psychological mechanisms and the factors influencing them. To that end, we defined contour as the degree of curvature, encompassing previous definitions in terms of concave–convex curviness (Schmidtmann et al., 2015) and empirical manipulations contrasting curved vs angular versions of the same basic shape (e.g., Bertamini et al., 2016; Bar & Neta, 2006). Moreover, we hypothesised that *contour* and *shape* are continuous, multidimensional and intertwined theoretical constructs characterising a *figure*: Continuous because there is a continuum of contours from extremely curved to extremely sharp-angled and between very rounded to very spiky shapes. Multidimensional because contour and shape are determined by multiple basic geometric features such as the number and degree of protrusions. Intertwined because their extremes conflate into the same figures: a circle is perfectly round and curved, and a pointed star is spiky and angular. This research shows that such considerations are central to explaining the *curvature effect*.

This approach allowed us to investigate the role of geometric features of the stimuli and individual and contextual factors in driving perceptual and hedonic evaluations, and how they relate at the individual and group levels. In so doing, we addressed the fundamental question of how perception and appreciation relate. In particular, we tested the hypothesis that perceptual evaluations would predict hedonic evaluations. As curved contours are more easily detected and processed (Bertamini et al., 2019; Yue et al., 2020), testing this hypothesis enabled exploring whether processing fluency (Chenier & Winkielman, 2009; Reber, 2012; Reber, Schwarz & Winkielman, 2004) would be responsible for the *curvature effect*. To further investigate the link between perception and appreciation, we probed whether the stimulus features affecting perceptual and hedonic evaluations would be the same, and whether people would use these parameters similarly when evaluating perceptually and hedonically. Our approach aimed to overcome the issues outlined above and further investigate the *curvature effect* as follows.

First, we identified three geometric features defining visual contour. We varied these parameters systematically and continuously to generate the Visual Contour (ViCo) stimulus set and devised computational measures to assess them. Then, we asked participants in an online behavioural experiment to judge each stimulus perceptually and hedonically in several ways, as described below.

Second, investigating individual variability allows assessing the extent to which a phenomenon like the *curvature effect* is genuine or a statistical averaging artefact (Clemente et al., 2021; Güçlütürk, Jacobs & van Lier, 2016), finding associated individual differences and, ultimately for our interest, unveiling the source of contour preferences and why the preference for curvature is so prevalent. To investigate hedonic evaluation, Nadal and colleagues (Clemente, Friberg & Holzapfel, 2022a; Clemente, Pearce & Nadal, 2022b; Clemente et al., 2021; Corradi et al., 2020) proposed a new conception of *aesthetic* or *hedonic sensitivity*. It is defined as the degree to which a specific feature influences someone's liking and is measured as the individual slope in linear mixed-effects models. These authors showed how wide variability in individual hedonic evaluations was masked by averaging. This sensitivity idea can be applied to perceptual evaluations of visual contour, which allowed us to inquire into perceptual and hedonic evaluations and their relationships at the group and individual levels by inspecting perceptual and hedonic sensitivities to geometric features characterising visual contour.

The third dimension of the proposed approach rests upon the fact that individual (e.g., personality, familiarity, expertise, affective reactivity) and contextual (e.g., experimental task) factors are known to influence hedonic evaluations (Cotter et al., 2017; Gollwitzer & Clark, 2019; Landy & Piazza, 2019; Palumbo & Bertamini, 2016; Vartanian et al., 2019). Likewise, perceptual evaluations seem to be affected by individual differences (Powell et al., 2016; Skewes et al., 2015; Zaidel et al., 2015). Regarding personal factors, we examined the impact of *art experience*—involving interest and knowledge in visual art (Chatterjee, Widick, Sternschein, Smith II & Bromberger, 2010)—, *openness to experience*—a personality trait captured by the abridged personality inventory (Gosling, Rentfrow & Swann, 2003)—and *need for cognition*—denoting a preference for cognitively-demanding objects and activities (Cacioppo & Petty, 1982)—on perceptual and hedonic sensitivities—i.e., the way people use a particular stimulus feature in their perceptual and hedonic evaluations, respectively (Clemente, 2022). As for the experimental conditions, we probed the impact of question polarity—i.e., asking about curved or angular—, response laterality—i.e., the position of the angular and curved ratings on a continuous scale—and the experimental paradigm—i.e., whether evaluations are made according to an internal (absolute) standard or by comparison to an external reference. We expected moderation effects, such that people scoring higher in these scales would be more prone to like effortful or unusual angular contours due to familiarity acquired through art experience, or reflecting a tendency to seek and prefer unusual or cognitively demanding objects and experiences involving angular contours—as manifestations of openness to experience and need for cognition, respectively.

To investigate the *curvature effect* while accounting for these factors efficiently and meaningfully, this research is structured into four studies conducted within the same experimental session using the same stimuli and the same cohort of participants. After presenting the general Method, subsequent sections are devoted each to a particular study. To probe the effects of context, the first two studies are characterised by distinctive experimental paradigms and comprise a hedonic and a perceptual task: **Study 1. Slider** investigates continuous liking for and perception (curved–angular) of the ViCo stimuli with no time constraints. **Study 2. Method of constant stimuli** examines general perceptual sensitivity (*d*') and binary preference in paired comparisons of the ViCo stimuli—i.e., between a *target* contour and an invariable contour *reference*—manipulating question polarity—i.e., asking about curviness or angularity. **Study 3. Relations between perception and appreciation** addresses the nature of the psychological mechanisms driving contour appreciation, testing the hypothesis that perceptual abilities and evaluations would underlie hedonic evaluations. **Study 4. Relations between sensitivities and other traits** inspects the role of art experience, openness to experience and need for cognition in the impact of the stimulus properties on hedonic and perceptual evaluations.

To our knowledge, this research is the first to introduce a multidimensional parametrisation of visual contour and systematically compare different experimental paradigms, so there is no previous literature informing hypotheses on the specific effects of such manipulations. Nevertheless, our primary aim was to test the *curvature effect*. Therefore, our null, general hypothesis was that the *curvature effect* would be robust to our manipulations. Each study tested concrete hypotheses regarding the experimental manipulation wherever possible and included the exploratory investigation of the aspects for which hypotheses could not be drawn based on previous research. Consequently, each study addressed specific aims, applying the most suitable analytical approaches and involving an interim discussion. Finally, a General Discussion takes a higher-level perspective on this research, and the take-home messages are summarised in the Conclusion. The technical implementation of the data analyses is presented in the Appendix. For the sake of conciseness, we only report statistically significant results ($p < .05$). The raw data and methodological tools are available at https://osf.io/kv38d/.

Method

Participants

Eighty-seven adults (64 women and 23 men, aged 18–70 years, $M = 34.20$, $SD = 12.35$), residents in the UK with English as their first language and recruited through Prolific (https://www.prolific.co/) with a minimum approval rate of 80%, completed the study using laptops or computers of minimum 13 inches and 4 Mbps internet connection—data collected from 18/02/2021 to 30/04/2021 and accessed on 30/04/2021. Previous research in the lab using mixed-effects models with random effects per participant and per stimulus consistently employed sample sizes of around 40 participants (e.g., Clemente et al., 2022, 2022b, Corradi et al., 2020). Following recommendations for online studies (Sauter, Draschkow & Mack, 2020; Stewart, Chandler & Paolacci, 2017), we doubled this sample size. According to Judd, Westfall and Kenny's (2016) power calculator (https://jakewestfall.shinyapps.io/two_factor_power/), our experimental design, in which 87 participants rated 80 stimuli in each study and condition, would have a power of 1 for a 0.5 effect size, which was expected by default given the lack of previous research with our experimental manipulations.

All participants reported normal or corrected-to-normal vision, not having accessed NHS mental support over the previous 12 months, not having been diagnosed with mild cognitive impairment or dementia and not having received a formal clinical diagnosis of autism spectrum disorder. The participants were unaware of the study's purpose, provided informed consent before participating and were compensated for participation following Prolific recommendations. The experiment comprising all studies was conducted following the Declaration of Helsinki and received approval from the Ethics Committee of the Cardiff Metropolitan University's School of Art & Design (approval number: 01_1617_F [NR]).

Materials

We generated the ViCo, a novel visual contour stimulus set consisting of black contours (closed lines) on white background varying systematically in the number of alternating inward and outward *vertexes* (v) or curve apexes (10, 12, 14, 18, 22, 26) within two concentric circumferences (Figure 1A), the *distance* (d) between contiguous vertexes (0–1, normalised units) (Figure 1B) and the *tension* (t) of the curve connecting them (0–1) (Figure 1C). In qualitative, lay terms, the *vertexes* mark the maximum concavity or convexity along the closed line, the *distance* determines how pronounced such protuberances are, and the *tension* defines how curvilinear or rectilinear is the line connecting the *vertexes*. To generate the set, we first drew two concentric rings with radii $1.5 \pm D/2$, respectively (i.e., separated by a distance D), with D ranging from 0 to 3 (0 corresponding to two fully overlapping rings and 3 to a point and a ring). We then placed half of the vertexes along the inner ring and the other half along the outer ring. To incorporate independent variability, we added small random shifts to each vertex both in the radial and angular directions—following a normal distribution with standard deviation $SD_r = 0.2D$ along the radial direction, and a normal distribution with angular standard deviation $SD_a = 0.2*2\pi/2v$ (in radians) along the angular direction. After adding the random shifts, we inspected the stimuli generated for different values of D and observed that values above 1.3 often yielded inconsistent results.

We thus restricted *D* to the range 0–1.3 and rescaled this parameter to 0–1 to obtain the aforementioned parameter d. Finally, minimal *tension* (0) was defined by a cubic Hermite spline interpolating the vertexes, whereas maximal *tension* (1) corresponded to straight lines forming a polygon. Stimuli with intermediate *tension* values were obtained by linear interpolation between maximal and minimal *tension* curves. All contours encompass the same area. The tool to generate the stimuli is a customisable, open resource for research available at https://github.com/compaes/ViCo.

For the present research, we selected two levels of *vertexes* (14, 22), four levels of *distance* (0.1, 0.4, 0.7, 1), and 11 levels of *tension* (0–1). All possible combinations of parameters made a total of 88 stimuli, distributed into eight blocks, each with a particular combination of *vertexes* and *distance* and 11 degrees of *tension* (Figure 1). Each stimulus was preceded by a fixation image (Thaler, Schütz, Goodale & Gegenfurtner, 2013) over a randomised duration between 500 and 1000 milliseconds[1] to prevent the influence of the aftereffect (Thompson & Burr, 2009) of seeing the persistent silhouette of a stimulus when a new stimulus was presented. The selected stimuli, the fixation, the custom-made question mark used in the experiment and the survey code are freely available at https://osf.io/kv38d/.

[1] To implement this protocol in Qualtrics, we developed a custom code included in the open-access survey code, publicly accessible at https://osf.io/kv38d/.

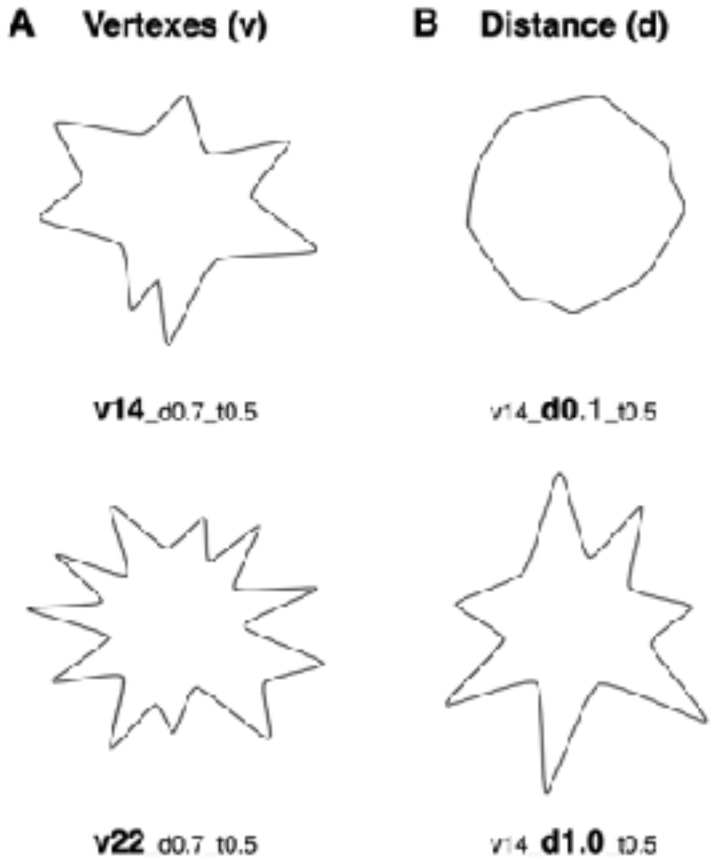

Figure 1. Examples of visual stimuli used in the experiment. The stimuli varied systematically in the number *vertexes* (v), the *distance* (d) between internal and external vertexes and the *tension* (t) of the curve connecting adjacent vertexes. The figure shows extreme values for each dimension in each column (e.g., right column: t = 0 vs t = 1) while keeping the rest constant (e.g., right column: v = 22 and d = 0.7).

After completing the tasks, the participants responded to three questionnaires: First, the Art Experience Questionnaire (AEQ; Chatterjee et al., 2010) assesses art interest and knowledge. Second, the Ten Item Personality Inventory (TIPI; Gosling et al., 2003) estimates *extraversion*, *agreeableness*, *conscientiousness*, *emotional stability* and *openness to experience*, although we only considered openness to experience in this research. Third, the Need for Cognition scale (NFC; Cacioppo et al., 1984) measures the tendency to engage in and enjoy thinking and cognitive challenges (Cacioppo & Petty, 1982). Ratings were given on the original Likert scales: 0–5 or 0–6 for the AEQ, a 7-point scale anchored by *disagree strongly* (1) and *agree strongly* (7) for the TIPI, and a 9-point scale using specific labels for each response and anchored by *very strong disagreement* (-4) to *very strong agreement* (+4) for the NFC.

Procedure

The experiment was conducted online, using Qualtrics to create and host it (https://www.qualtrics.com). The participants undertook the experimental tasks in full-screen mode. They were first welcomed and briefed about the entire procedure. Then, they declared that they met the study's requirements (i.e., using updated versions of Chrome, Firefox or Safari, ensuring that the browser was on 100% zoom, maximising the browser window, and switching off phone/e-mail/music and any possible distractor) and expressed their informed consent to participate and for us to use their anonymised data. A total of 87 participants judged each of the 88 stimuli using two experimental paradigms, each consisting of a hedonic and a perceptual task. Thus, they assessed each stimulus four times. The participants were guided through the tasks by standard onscreen instructions. After completing the four tasks, the participants answered the computer-based questionnaires. The experimental session lasted around 50 minutes.

Study 1: Slider

We first used a slider paradigm to investigate hedonic and perceptual ratings of contours. Based on previous research, we hypothesised that the curvature effect would be robust to our multidimensional and continuous manipulation of contour, so that the participants would like more contours with lower *tension*, as we expect this dimension to be the primary determinant of contour. The lack of previous research using our approach precluded us from drawing specific hypotheses on the impact of the other parametrised dimensions and their interactions. Therefore, the corresponding results are exploratory.

Procedure 1

We applied this paradigm in a hedonic and a perceptual task, in this particular order. In both tasks, ratings were self-paced, and the order of the stimuli was individually randomised.

In the **hedonic task**, the participants rated their liking for each stimulus on a 21-point Likert scale displayed as a slider and anchored by *extremely dislike* (-10, left end) to *extremely like* (10, right end). Participants were requested to base their responses on the subjective feelings of pleasure, interest, enjoyment and desirability evoked or elicited by the stimulus. The following question at the top of the screen reminded them of the task: “How much do you like the contour below?”

In the **perceptual task**, the participants rated how curved–angular they perceived each contour on a similar 21-point Likert scale anchored by *extremely angular* (-10, resp. 10) to *extremely curved* (10, resp. -10), with response *laterality* (left–right) randomised between participants. The question was neutral regarding curvature vs angularity: “Where would you place the contour below?”

Data analysis 1

Hedonic ratings and sensitivities.

Following Nadal and colleagues’ (Clemente et al., 2021, 2022b, 2022a; Corradi et al., 2020) approach, we fitted a linear mixed-effects model (Hox, Moerbeek & van de Schoot, 2010; Snijders & Bosker, 2012) to assess the effect of *vertexes*, *distance* and *tension* on participants’ liking for the stimuli. The models were set up to reflect the effects of the main predictors on the 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 included *vertexes*, *distance* and *tension* and their interactions as fixed effects, intercepts and slopes as random effects within participants, and intercepts as random effects within stimuli. A visual inspection of the stimuli suggested that those with d = 0.1 could be deemed a different shape: a rounded one as opposed to a star-like shape of stimuli with d > 0.1. To test this possibility, we re-ran the analysis excluding d = 0.1. If a bias were confirmed, we would use the model excluding those stimuli because our primary interest here was contour, not shape.

Mixed-effects modelling provides estimates for group-level effects—which can be compared with those of previous studies—and participant-level effects—corresponding to the individual intercepts and slopes. We extracted the individual slopes from the random-effect structure and used them as our measure of hedonic sensitivity to *vertexes*, *distance* and *tension*. Shapiro-Wilk tests informed about the normality of the distributions of sensitivities.

Perceptual ratings and sensitivities.

We applied the same analytical method to evaluations of perceived contour. Namely, we fitted a linear mixed-effects model to assess the effect of *vertexes*, *distance* and *tension* on the participants' perceptual ratings. This model included *vertexes*, *distance*, *tension*, label *laterality* and their interactions as fixed effects, intercepts and slopes as random effects within participants, and intercepts as random effects within stimuli. Following the rationale above, we tested the impact of d = 0.1 and excluded these stimuli if they biased the results. Finally, we extracted the individual slopes to define perceptual sensitivities to *vertexes*, *distance* and *tension* for each participant and tested the normality of the sensitivity distributions.

Results 1

Hedonic ratings and sensitivities.

Removing any of the effects did not significantly improve the model fit (all *p*s > .05), so we retained all parameters in the full model ($r^2_m = .15$, $r^2_c = .61$). Overall, liking increased with increasing *vertexes* and *distance*, decreased with increasing *tension,* and the effects of *distance* were enhanced for more *vertexes.* The effect sizes were small for *distance* and very small for the other predictors (Table 1).

Table 1. *Linear Mixed-effects Models of Hedonic Evaluations*

Model	Predictor	ß	*df*	*t*	*p*	*d* [95% CI]
Including *distance* = 0.1	***Vertexes***	0.75	112.59	4.05	< .01	0.18 [0.09, 0.26]
	Distance	1.54	90.62	6.47	< .01	0.36 [0.25, 0.48]
	Tension	-0.30	116.60	-3.77	< .01	-0.07 [-0.11, -0.03]
	Vertexes:Distance	0.70	80.00	7.13	< .01	0.17 [0.12, 0.21]
Excluding *distance* = 0.1	***Vertexes***	1.10	89.49	4.89	< .01	0.29 [0.17, 0.40]
	Distance	0.83	89.25	6.95	< .01	0.22 [0.16, 0.28]
	Tension	-0.39	89.80	-4.43	< .01	-0.10 [-0.15, -0.06]
	Vertexes:Distance	0.43	58.00	5.60	< .01	0.11 [0.07, 0.15]

Note. Positive slopes denote greater liking for more *vertexes*, greater *distance* and more *tension*. Negative slopes denote greater liking for fewer *vertexes*, smaller *distance* and less *tension*. ß refers to the estimated group-level slope, *df* to degrees of freedom, *t* to *t*-value, *p* to *p*-value, and *d* to effect size.

In the model excluding d = 0.1, removing any of the effects did not significantly improve the model fit (all *p*s > .05), so we used the full model ($r^2_m = .08$, $r^2_c = .58$). Again, liking increased with *vertexes* and *distance,* decreased with *tension*, and the effects of *distance* were enhanced for more *vertexes*. The effect sizes were small for *vertexes* and *distance* and very small otherwise (Table 1).

Figure 2 suggests that the stimuli with d = 0.1 were generally disliked, whereas the rest were mostly liked, and that d = 0.1 mitigated the effects of *vertexes* and *tension*. The divergences between the models' estimates concur with that interpretation. Therefore, we extracted the individual slopes from the model without d = 0.1 as our measures of hedonic sensitivities. The distributions of sensitivities show wide variability in how the geometric features affected individual evaluations, ranging from negative—denoting preference for fewer *vertexes* (*n* = 22), smaller *distance* (*n* = 14) and lower *tension* (*n* = 67), respectively,—to positive—denoting preference for more *vertexes* (*n* = 65), greater *distance* (*n* = 73) and higher *tension* (n = 20)[2], respectively. Only hedonic sensitivities to *vertexes* were normally distributed (Table 2).

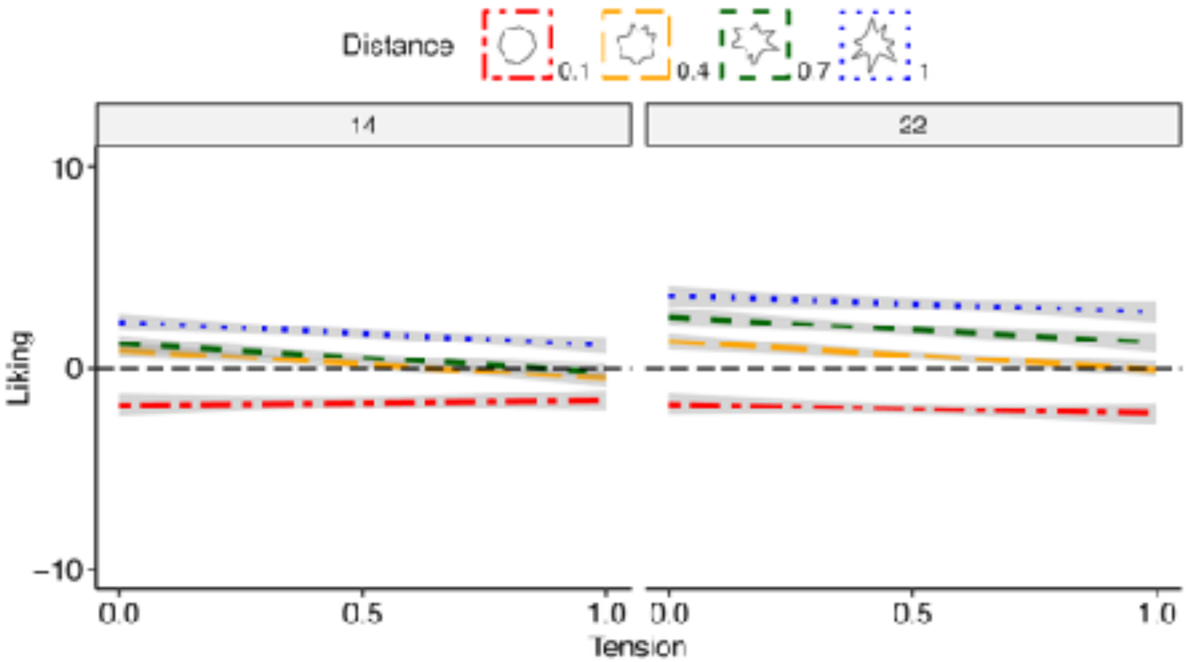

Figure 2. Hedonic evaluations of visual contour in the original rating scales. The horizontal dashed black line marks hedonic indifference. The columns distinguish the two levels of *vertexes*. Shaded areas correspond to 95% CI.

2 These subsamples represent participants with sensitivities either below or over zero, i.e., from insensitivity (0) to high sensitivity in either direction (negative or positive).

Table 2. *Distributions of Hedonic Sensitivities to Geometric Features*

Geometric feature	*M*	*SD*	Shapiro–Wilk Tests				Range
			W	*p*	Skewness	Kurtosis	
Vertexes	1.10	1.89	0.99	.29	-	-	[-5.04, 5.55]
Distance	0.83	1.02	0.96	.01	-0.67	1.29	[-2.65, 3.24]
Tension	-0.39	0.68	0.95	< .01	-0.38	0.99	[-2.15, 1.79]

Note. M stands for mean estimated sensitivity, *SD* for standard deviation, *W* for the *t*-value of the Shapiro–Wilk test, and *p* for its *p*-value. Skewness and kurtosis are reported for non-normal distributions ($p \leq .05$). Range refers to the minimum and maximum hedonic sensitivities—i.e., the individual liking slopes in the mixed-effects models, or how increments on each dimension affect individual liking.

Perceptual ratings and sensitivities.

Removing any of the effects did not significantly improve the model fit (all *p*s > .05), so we used the saturated model ($r^2_m = .40$, $r^2_c = .74$). Overall, perceived curviness decreased with *vertexes*, *distance* and *tension*, and the effects of *tension* were enhanced for smaller *distance* and for more *vertexes* when the curviness label was on the right of the slider. The effect sizes were moderate for *distance*, small for *tension* and *vertexes*, and very small for the interactions (Table 3).

Table 3. *Linear Mixed-effects Models of Perceptual Evaluations*

Model	Predictor	ß	*df*	*t*	*p*	*d* [95% CI]
Including *distance* = 0.1	***Vertexes***	-1.31	108.90	-3.56	< .01	-0.23 [-0.36, -0.11]
	Distance	-2.47	124.19	-6.71	< .01	-0.44 [-0.57, -0.31]
	Tension	-2.23	143.51	-7.44	< .01	-0.40 [-0.50, -0.29]
	Distance:Tension	-0.45	87.71	-2.55	< .01	-0.08 [-0.14, -0.02]
	Vertexes:Tension:Laterality	0.34	7220.00	2.53	.01	0.06 [-0.01, 0.11]
Excluding *distance* = 0.1	***Vertexes***	-1.55	107.00	-8.47	< .01	-0.32 [-0.39, -0.25]
	Distance	-0.66	112.70	-6.83	< .01	-0.14 [-0.18, -0.10]
	Tension	-2.54	100.00	-12.54	< .01	-0.53 [-0.61, -0.44]
	Vertexes:Tension:Laterality	0.44	5328.00	3.27	< .01	0.09 [0.04, 0.15]

Note. Estimated perceived curviness across conditions. ß refers to the estimated group-level slope, *df* to degrees of freedom, *t* to *t*-value, *p* to *p*-value, and *d* to effect size.

In the model excluding d = 0.1, removing any of the effects did not significantly improve the model fit (all *p*s > .05), so we retained all parameters in the full model (r^2_m = .32, r^2_c = .73). Overall, perceived curviness decreased with *vertexes*, *distance* and *tension*, and the effects of *tension* were enhanced for more vertexes and when the curviness label was on the right of the slider. The effect sizes were moderate for *tension*, small for *vertexes* and very small otherwise (Table 3).

Figure 3 suggests that the stimuli with d = 0.1 were categorised differently, and that d = 0.1 mitigated the effects of *vertexes* and *tension*. The divergences between the models' estimates concur with that interpretation. Therefore, following the same criteria as for hedonic sensitivities, we extracted the individual slopes from the model without d = 0.1 as our measures of perceptual sensitivities. The distributions of sensitivities show wide variability in how the geometric features affected perceptual evaluations, ranging from negative—denoting higher perceived curviness (resp. lower perceived angularity) for fewer *vertexes* (*n* = 84), smaller *distance* (*n* = 80) and lower *tension* (*n* = 81), respectively—to positive—denoting higher perceived curviness (resp. lower perceived angularity) for more *vertexes* (*n* = 3), greater *distance* (*n* = 7) and higher *tension* (*n* = 6), respectively. The results suggest that each of these parameters affected perceptual ratings in opposite directions in different participants. Only the perceptual sensitivities to *tension* were normally distributed (Table 4).

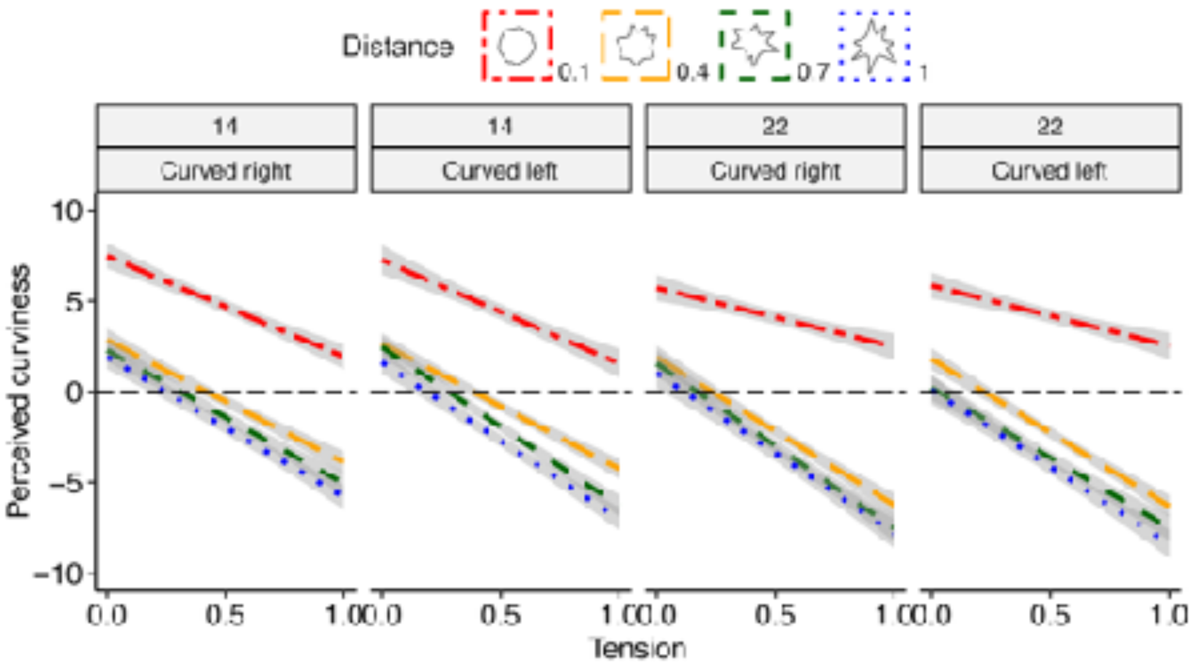

Figure 3. Perceptual evaluations of visual contour. More positive values in the *y*-axis mean that the stimulus was rated as more curved, whereas more negative values in the *y*-axis mean that the stimulus was rated as more angular. The horizontal dashed line marks the perceptual contour threshold. The columns distinguish the two levels of *vertexes* and *condition*—i.e., the position of the curved label on either side of the slider. Shaded areas correspond to 95% CI.

Table 4. *Distributions of Perceptual Sensitivities to Geometric Features*

Geometric feature	*M*	*SD*	Shapiro–Wilk Tests				Range
			W	*p*	Skewness	Kurtosis	
Vertexes	-1.55	1.00	0.96	< .01	0.27	2.30	[-4.75, 1.98]
Distance	-0.66	0.57	0.96	0.02	0.08	1.89	[-2.64, 1.15]
Tension	-2.54	1.73	0.99	0.46	-	-	[-5.98, 1.56]

Note. M stands for mean estimated sensitivity, *SD* for standard deviation, *W* for the *t*-value of the Shapiro–Wilk test, and *p* for its *p*-value. Skewness and kurtosis are reported for non-normal distributions ($p \leq .05$). Range refers to the minimum and maximum perceptual sensitivities—i.e., the individual slopes in the mixed-effects model, or how increments on each dimension affect perceived curviness.

Discussion 1

Our stimulus characterisation exposed the relation between *contour* and *shape*, lending support to the view that they are distinct but intermingled theoretical constructs describing a figure, determined by common geometric features and, therefore, prone to be confounded. Indeed, we certainly lack terms to differentiate contour and shape neatly: terms like *angular*[3] and *curved* are applied to both shape and contour. Thus, an interesting line of investigation would be to explore the distinctions between contour and shape[4], the parameters contributing to their properties and their influence on perceptual and hedonic evaluations. In this line, the participants in this study rated the stimuli with d = 0.1 unlike the rest, suggesting a different shape category. Indeed, due to the random shift, contours with d = 0.1 did not distinguish alternating outward and inward vertexes. Instead, most vertexes actually pointed

[3] Although *sharp-angled* has been traditionally used in the literature when contour is manipulated in a dichotomous or categorical way, it does not solve the problem of differentiating contour from shape.

[4] In this regard, we speculate that contour refers to the local, fine-grained contrast perimeter, whereas shape refers to the global categorization of the figure. Of course, this intuition requires proper scientific testing beyond the scope of this study.

outwards, which resulted in a more rounded shape. Thus, the vertexes' spatial distribution emerged as a relevant factor defining shape and affecting perceptual and hedonic evaluations. In this regard, the results align with Friedenberg and Bertamini (2015) in that participants tended to like more start-like shapes, i.e., with more concavities. Interestingly, the results also suggest a different weighting of *distance* and *tension* in each kind of rating: While the vertexes' spatial distribution between d = 0.1 and d = 0.4 distinguished shape categories, *tension* was the main determinant of perceptual evaluations of curved–angular when excluding stimuli with d = 0.1. Future research ought to factor vertexes' location in and further investigate its effects together with our proposed parameters in controlled configurations.

The correspondence between the geometric features characterising contour (e.g., *tension*) and psychological attributes like threat is one of the main questions that literature on the *curvature effect* has raised but has not yet resolved (Bertamini et al., 2016; Palumbo et al., 2015). Our research goes further than previous studies in distilling the dimensions that may contribute singularly and in interaction to contour (and shape) preference. Thus, it paves the way to investigate its underlying psychological mechanisms. Research in empirical aesthetics should not neglect the paramount importance of the aesthetic association principle (Fechner, 1866, in Ortlieb, Kugel & Carbon, 2020) and prototypicality (Blijlevens, Carbon, Mugge & Schoormans, 2012) in evaluative judgments. Clemente and colleagues (2021) suggested that an amodal preference for smooth contours might be associated with a general affective sensitivity. In this regard, greater *tension* might relate to more threatening or unusual contours. Our stimuli's relatively abstract and unfamiliar nature prevents direct associations with real objects loaded with semantic content, affective connotations and previous affective or hedonic experiences. Emotional cues such as colour and allusions to real objects are avoided across stimuli, which minimises variation in perceived affect due to factors other than the dimensions manipulated. The only remaining, immanent figurative allusions are those to more or less round or star-like shapes defined by *vertexes* and *distance*.

In this regard, the results disprove associations usually claimed to be responsible for the *curvature effect*. On the one hand, preference for prototypical figures should be reflected in interactive effects of *distance* and *tension* on liking, which contradicts the results. On the other hand, it is reasonable to suppose that threat would be associated with more pointy star-like figures, and that these should, therefore, be less liked overall if threat were a factor driving evaluative judgments (Palumbo et al., 2015). Instead, the participants tended to like more star-like figures with more points (i.e., with more *vertexes* and greater *distances*). We speculate that a preference for complexity might account for these effects (Van Geert & Wagemans, 2020; Nadal et al., 2010). Nevertheless, the current data do not enable us to ascertain the psychological attributes (if any) that the participants might have assigned to the stimuli. Further research is required to elucidate the relations between these constructs or attributes and the geometric features manipulated.

In summary, the results of Study 1 support our claim that contour and shape are multidimensional and intertwined theoretical constructs. In addition, our findings show the usefulness of considering this complexity to disentangle the contributions of geometric features to each construct and investigate phenomena like the *curvature effect* and its underlying psychological mechanisms.

Study 2: Method of Constant Stimuli

We applied the method of constant stimuli (Simpson, 1988) to perceptual and hedonic evaluations, respectively. This procedure had two main purposes: to test the hypothesis that the curvature effect would be robust to pairwise comparisons between different levels of *tension* and the median while controlling for *vertexes* and *distance*, and to explore the role of perceptual sensitivity on contour preference.

Procedure 2

For each block with a particular level of *vertexes* and *distance*, the participants compared the target contour in each level of *tension* with the reference contour with median *tension* (0.5). Responses were two-alternative forced choices (2AFC) with the Yes/No buttons on either side of the screen. Participants were assigned to a *condition* (curved or angular) to address question polarity in the perceptual task—i.e., they were asked about curviness or angularity—and to 125 ms, 250 ms or 500 ms *time exposure* in both tasks as a control variable. The assignment of each participant to a specific *condition*, *time exposure*, *laterality* of the target stimulus (left–right) and the (Yes/No) response buttons on the screen, block order and stimulus order was individually randomised.

In the **perceptual task**, the participants were asked to compare the target with the reference regarding its curvature or angularity. Thus, they answered the question at the top of the screen: “Is the contour on the *left*/*right* more *curved*/*angular* than the reference?”

In the **hedonic task**, the participants compared the target to the reference in terms of preference. Thus, they answered the question at the top of the screen: “Do you like the contour on the *left*/*right* more than the reference?”

Data analysis 2

Perceptual sensitivity index (d’).

We assessed the participants’ ability to detect minute differences in *tension* for each level of *vertexes* and *distance* (i.e., within each block) in both *conditions* (i.e., when asked about curviness or angularity). That is, we computed the *d’* for each participant and block, a general perceptual sensitivity index. This measure reflects the distance between the distributions of signal and signal-plus-noise and corresponds to the *z*-value of the hit rate minus that of the false-alarm rate (Macmillan & Creelman, 2005). The signal was set to angular (t = 1.0). First, we tested whether the *d’*s were significantly different from zero and whether responses in each *condition* (asking about curviness or angularity) were biased as determined by the *c* criterion—which refers to the number of standard deviations from the midpoint between the two *condition* distributions—through one-sample two-tailed *t*-tests. We then tested the effects of *vertexes*, *distance*, *condition* and their interactions on the *d*’s through linear mixed-effects analysis. The model included random intercepts per block and participant.

Binary preference.

First, descriptive statistics were used to investigate a general preference for the target or the reference. We wanted to ascertain whether people consistently prefer lower *tension*, as the *curvature effect* would predict. To that end, one-sample two-tailed *t*-tests determined whether the preferred *tension* was different from the median (t = 0.5).

Second, to probe the effect of block (i.e., shape) on preferred *tension*, we modelled preferred *tension* as a function of *vertexes*, *distance* and their interactions. The linear mixed-effects model followed the approach above and included intercepts as random effects per participant and stimulus.

Results 2

Perceptual sensitivity index (d').

Here, we report the descriptive statistics for *d*' in each condition: curved ($M = 0.31$, $SD = 0.67$) and angular ($M = 0.60$, $SD = 0.64$). The participants' *d'*s per block turned out to be significantly different from zero and positive ($t = 17.22$, $df = 695$, $p < .01$, $d = 0.65$), suggesting that their performance was above chance level. Besides, the *t*-tests for the *c* criterion per *condition* suggested that the responses were not biased (angular: $t = -0.84$, $df = 311$, $p = .80$, $d = -0.05$; curved: $t = -22.406$, $df = 383$, $p = 1$, $d = -1.14$). Removing any of the effects in the models of *d*' as a function of *vertexes*, *distance*, *condition* and their interactions did not significantly improve the model fit (all *p*s > .05). In the saturated model ($r^2_m = .05$, $r^2_c = .43$), the mixed-effects analysis revealed significant effects of *condition* with moderate effect size (ß = -0.31, $t_{(171.48)} = -2.65$, $p < .01$, $d = -0.44$ [-0.72, -0.15]), suggesting that the participants responded more accurately when asked about angularity than when asked about curviness.

Binary preference.

The participants preferred the reference over the target in 57% of responses, entailing a general preference for medium *tension* (t = 0.5) when *distance* and *vertexes* were controlled. Across participants and stimuli, people preferred slightly lower *tension* ($M = .47$, $SD = .21$) even when disregarding preferences for the reference and considering only preferences for the target (M = .43, SD = .31). However, the one-sample t-tests revealed that these averaged preferences were not significantly different from the preference for the reference with median *tension* (ps = 1).

In the models of preferred *tension* as a function of block characteristics, removing fixed effects did not significantly improve the model fit (all ps > .05). The saturated model ($r^2_m = .00$, $r^2_c = .08$) showed no significant effects of *vertexes* or *distance* independently or in interaction (all ps > .05).

Discussion 2

The participants were able to consistently discern differences in *tension* in figures with equal *vertexes* and *distance*. However, they were more accurate when framing the comparisons in terms of angularity than curviness. Such a higher accuracy when asked about angularity may be due to the most angular (greatest *tension*) contours being the baseline (signal) for correctness from which potentially infinite degrees of curviness differentiate and, therefore, easier to incorporate as a conceptual mind frame. Indeed, there was a maximal physical *tension* (i.e., straight lines in the signal), whereas all other figures in the same block presented different degrees of sinuosity. Therefore, when looking for differences in angularity, participants could rely on an actual absolute reference, so the task would primarily rely on visual acuity. Further research is needed to probe whether this is the case. In contrast, asking about curviness prevented any obvious reference, since the minimum *tension* here is an arbitrary curvature maximum not so easily identifiable compared to other *tension* levels.

The results of this study are particularly relevant for testing the *curvature effect*. When forced to express a binary preference against the median *tension* while controlling for *vertexes* and *distance,* the participants tended to prefer the median *tension* over the rest consistently. Crucially, these results question the *curvature effect*, or at least show a vital limitation: It does not hold in 2AFC settings where a contour with medium *tension* is compared with any contour varying only in *tension* along a continuum between straight lines and a cubic spline. The contours with median *tension* were systematically preferred, which might be masked when comparing extremely curved (i.e., minimal *tension*) and angular (maximal *tension*) contours (e.g., in Bertamini et al., 2016; Clemente et al., 2021; Corradi et al., 2020). It seems plausible that the participants preferred the median *tension* because it was the reference and, thus, familiarity drove preference in this paradigm. However, we did not find effects of presentation order, and such a preference for median *tension* was robust even when disregarding trials in which the reference was preferred. In addition, we systematically varied *tension* across combinations of *vertexes* and *distance*, which defined more or less round or star-like basic figures. Thus, if taking a spiky star or a perfect circle as prototypes, it stands to reason that their extreme levels of *tension* for those levels of *vertexes* and *distance* ought to be preferred over the rest. However, this is not what the results revealed. Instead, people consistently preferred median *tension* across blocks, that is, across combinations of *vertexes* and *distances* defining shapes.

In summary, the method of constant stimuli revealed a finding of paramount importance for our purposes: the *curvature effect* is not robust to pairwise comparisons or binary preference settings.

Study 3: Relations Between Perception and Appreciation

A primary and overarching goal of this research was to clarify how perception and appreciation relate to explaining the *curvature effect*. We addressed this question at the group level, inspecting raw ratings, and at the individual level, inspecting sensitivities and the association between perceptual ability (*d*') and binary preference.

Data analyses and results 3

Relations between perceptual and hedonic ratings.

We wished to ascertain the influence of perception on liking. For that purpose, we ran a multiple-regression analysis of raw liking ratings on raw perceptual ratings (Study 1). The saturated model included linear and quadratic perceptual ratings and their interactions as predictors.

Removing effects in the saturated regression of continuous liking ratings on continuous perceptual ratings did not significantly improve the model fit ($p > .05$). In this model ($r^2 = .03$), linear (ß = -0.13, *se* = 0.01, $t = -15.26$, $p < .01$, $d = -0.17$ [-0.20, -0.15]) but not quadratic perceptual ratings predicted hedonic ratings significantly, albeit with very small effect size, suggesting that the more curved people perceived the contour, the less they tended to like it. However, when excluding d = 0.1, the association turned positive and quadratic (Figure 4). Removing either the linear or the quadratic terms significantly worsened the model fit ($p < .01$). The results of this saturated model ($r^2 = .02$) suggested that the more people deemed a contour as more curved, the more they tended to like it (linear term: ß = 0.07, *se* = 0.01, $t = 6.23$, $p < .01$, $d = -0.03$ [-0.06, 0.00]), although mild contours were the least liked (quadratic term: ß = 0.02, *se* = 0.00, $t = 10.25$, $p < .01$, $d = 0.13$ [0.10, 0.15]). The effect sizes were very small.

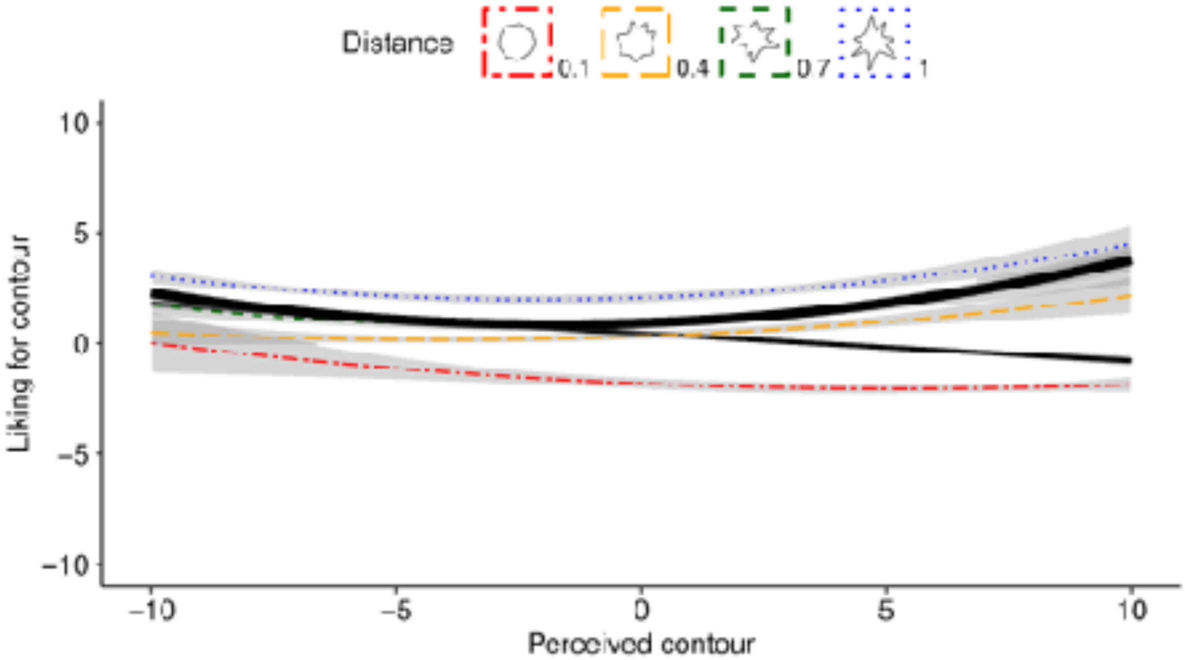

Figure 4. Hedonic ratings as a function of perceptual ratings with polynomial fitting. The coloured non-solid lines represent different *distance* levels. The solid thin black line represents the best fitting across *distance* levels. The solid thick black line represents the best fitting across *distance* levels excluding d = 0.1. In the *x*-axis, negative values denote less curved (resp. more angular), whereas positive values denote more curved (resp. less angular). Shaded areas correspond to 95% CI.

Relations between perceptual and hedonic sensitivities.

We wanted to elucidate whether the geometric features would similarly influenced perceptual and hedonic evaluations. To that end, we inspected Spearman correlations between hedonic sensitivities—i.e., the individual slopes from the liking model—and perceptual sensitivities—i.e., the individual slopes from the perception model—to the same geometric feature (Study 1). We chose a non-parametric test because the sensitivities were not assumed to be normally distributed—which was confirmed by the results of normality analyses in Study 1.

Spearman correlations between hedonic and perceptual sensitivities to the same structural feature indicated that only perceptual and hedonic sensitivities to *tension* correlated significantly ($\rho = .32$, $p < .01$), suggesting that the participants tended to rely on *tension* similarly for both hedonic and perceptual evaluations. In other words, people who perceived figures with lower *tension* as more curved also tended to like them more.

Relations between perceptual ability and preference.

We wished to clarify the extent to which perceptual ability drove contour preference. To that purpose, we regressed preferred *tension* on general perceptual sensitivity (*d*') for each *condition*.

Condition, i.e., asking about curviness or angularity (Study 2),was found to influence *d*', which supported running one model per *condition*. The regressions showed no significant effect of *d*' on preferred *tension* regardless of whether asking about curviness or angularity (all *p*s > .05).

Relations between perceptual ability and hedonic sensitivities.

We wanted to investigate the extent to which general perceptual sensitivity (*d*'), or the ability to perceive and categorise minute differences in *tension*, predicted hedonic sensitivities to *vertexes*, *distance* and *tension*. To that aim, we regressed each hedonic sensitivity (Study 1) on general perceptual sensitivity (*d*') for each *condition* (Study 2).

The results of regressing hedonic sensitivities on *d*' suggest that a higher ability to perceive and correctly categorise minute differences in *tension* when asked about angularity explained a tendency to like more figures with fewer *vertexes* and smaller *distance*. In contrast, such an ability only explained a tendency to like more figures with smaller *distances* when asked about curviness. The effect sizes were very small (Table 5).

Table 5. *Hedonic Sensitivities to Geometric Features Predicted by General Perceptual Sensitivity (*d*')*

Geometric feature	*Condition*	ß	*se*	*t*	*p*	*d* [95% CI]
Vertexes	**Angularity**	-0.32	0.05	-5.92	< .01	-0.10 [-0.13, -0.07]
	Curviness	0.03	0.04	0.70	0.48	0.01 [-0.02, 0.04]
Distance	**Angularity**	-0.29	0.03	-10.36	< .01	-0.17 [-0.21, -0.14]
	Curviness	-0.08	0.02	-3.48	< .01	-0.05 [-0.08, -0.02]
Tension	**Angularity**	-0.03	0.02	-1.53	0.13	-0.03 [-0.06, 0.01]
	Curviness	-0.03	0.02	-1.87	0.06	-0.03 [-0.06, 0.00]

Note. ß refers to estimated group-level slope, *se* to standard error, *t* to *t*-value, *p* to *p*-value, and *d* to effect size. Positive (resp., negative) values denote a positive (resp., negative) association between the perceptual ability to discern correctly differences in *tension* (*d*') and the tendency to like more figures with more *vertexes*, greater *distance* and greater *tension*.

Discussion 3

Perceptual ratings significantly predicted hedonic ratings, although with important caveats. When considering all stimuli, people tended to like more what they deemed less curved or more angular—refuting the *curvature effect*. However, when excluding stimuli with d = 0.1, higher perceived curviness positively predicted greater liking—supporting our hypothesis and the *curvature effect*—, although medium contours tended to be less liked. These results suggest an interference between *contour* and *shape* and that each geometric feature weighted differently to characterise these constructs: First, shape differences (driven by *distance*) dominated liking over contour differences (driven by *tension*). And second, only when shape differences were removed by excluding the stimuli with d = 0.1, the *curvature effect* emerged.

Perceptual and hedonic sensitivities to *vertexes* and *distance* were unrelated. Only sensitivities to *tension* correlated when excluding stimuli with d = 0.1. This provides some support for the impact of perceptual over hedonic evaluations but only concerning *tension*, which was the strongest predictor of perceived contour but the weakest predictor of liking in Study 1. So, it seems that, when relying on this feature, deeming a contour with lower *tension* as more curved tended to entail a greater liking for it. This hypothesis needs further testing in purposely controlled settings.

This study also reveals an important aspect regarding the psychological mechanisms underlying the *curvature effect*. General perceptual sensitivity (*d*'), or the ability to detect and correctly categorise minute differences in *tension*, was irrelevant for binary preference for different degrees of *tension*. In other words, when forced to express a binary preference against the median *tension* while controlling for *vertexes* and *distance,* the participants tended to consistently prefer the median *tension* over the rest regardless of their general perceptual sensitivity (*d*'). This result contradicts the hypothesis that the *curvature effect* would rely on perceptual abilities to detect differences in curvature (i.e., *tension*) and points to other (plausibly affective) mechanisms driving contour preference.

In addition, the results uncovered an effect of context. Namely, the mindset resulting from asking about curviness or angularity affected general perceptual sensitivity (Study 2) and biased how variations in each manipulated dimension affected liking. Still, the apparent conundrum is why the ability to detect minute differences in *tension* predicted greater liking for stimuli with smaller *distances* and fewer *vertexes*. A plausible explanation is that smaller *distance* and fewer *vertexes* facilitated the appreciation of *tension* differences, which participants with higher general perceptual ability enjoyed more.

Study 4: Relations Between Sensitivities and Other Traits

Assessing perceptual and hedonic sensitivities—i.e., the extent to which the manipulated geometric features affect perceptual and hedonic ratings, respectively—and general perceptual sensitivity (*d'*) enables testing the role of other individual traits on perception and appreciation. Previous results regarding hedonic sensitivities point to inconsistent effects of art experience, openness to experience and need for cognition on hedonic evaluations of visual contour (Clemente et al., 2021; Clemente et al., 2022a; Corradi et al., 2020). Nevertheless, we wished to elucidate whether some influences would be uncovered using our continuous and multidimensional manipulation. The novelty of our approach entails that no previous literature can substantiate specific hypotheses in this regard. However, it seems reasonable to expect that participants more open to experience, with more experience in art and with greater need for cognition would like more complex and star-like figures (i.e., with more *vertexes* and greater *distance*) and would tolerate and enjoy less curved contours (i.e., with greater *tension*), and that these traits would be positively linked to greater general perceptual sensitivity to minute variations in *tension* (*d'*).

Data analysis and results 4

To test the hypotheses above, we used multiple linear regression analyses. Namely, we examined the degree to which art experience, openness to experience and need for cognition explained between-subject variance in global perceptual sensitivity (*d'*) and perceptual and hedonic sensitivity to each geometric feature.

The results of the regressions of sensitivities on individual traits suggest the following (Table 6): Participants with more art experience—defined as more interest and knowledge in visual art—tended to perceive contours with higher *tension* as less curved and to like more contours with more *vertexes* and greater *distance*—albeit with very small effect sizes. Participants more open to experience tended to be more accurate in discerning minute differences in *tension* and to like more contours with more *vertexes*—albeit with very small effect sizes. Participants with greater need for cognition tended to be more accurate in discerning minute differences in *tension*, to rate contours with more *vertexes*, greater *distance* and lower *tension* as more curved, and to like more contours with lower *tension*—albeit with small effect size for perceptual sensitivity to *tension* and very small effect sizes otherwise.

Table 6. *Perceptual and Hedonic Sensitivities Predicted by Individual Traits*

Trait	Sensitivity	Feature	ß	*se*	*t*	*p*	*d* [95% CI]
Art experience	**Perceptual**	***Tension***	-0.16	0.06	-2.48	.01	-0.09 [-0.16, -0.02]
	Hedonic	***Vertexes***	0.36	0.07	5.15	< .01	0.19 [0.12, 0.26]
		Distance	0.18	0.04	4.58	< .01	0.17 [0.10, 0.24]
Openness to experience	***d'***		0.11	0.03	24.15	< .01	0.16 [0.08, 0.23]
	Hedonic	***Vertexes***	0.19	0.07	2.63	.01	0.10 [0.03, 0.18]
Need for cognition	***d'***		0.07	0.03	2.62	.01	0.10 [0.03, 0.18]
	Perceptual	***Vertexes***	0.11	0.04	2.72	.01	0.11 [0.03, 0.18]
		Distance	0.11	0.02	4.98	< .01	0.19 [0.12, 0.27]
		Tension	-0.40	0.07	-6.11	< .01	-0.23 [-0.31, -0.16]
	Hedonic	***Tension***	-0.06	0.03	2.36	.02	-0.09 [-0.17, -0.02]

Note. Horizontal lines separate the models. ß refers to estimated group-level slope, *se* to standard error, *t* to *t*-value, *p* to *p*-value, and *d* to effect size. Positive values denote a positive impact of the individual trait of interest on the tendency to perceive minute differences in tension or deem more curved or like more figures with more *vertexes*, greater *distance* or greater *tension*, respectively.

Discussion 4

Domain-specific experience (art interest and knowledge), personality (openness to experience) and cognitive-preference (need for cognition) traits explained some variability in the way people used the manipulated geometric features in their perceptual and hedonic evaluations. Whereas the trait need for cognition has only recently been explored in relation to hedonic evaluations and sensitivities (Clemente et al., 2022a; Clemente, Kaplan & Pearce, under review), the effects of art experience and openness to experience on liking enjoy vast empirical support (Chamorro-Premuzic, Reimers, Hsu & Ahmetoglu, 2009; Chatterjee et al., 2010; Furnham & Chamorro-Premuzic, 2004; Furnham & Walker, 2001; Rawlings, 2003; Rawlings, Barrantes i Vidal & Furnham, 2000). In this realm, our findings add to the relevance of these traits in hedonic evaluations and extend to perceptual evaluations of visual contour.

Higher scores in art experience were associated with enhanced perceptual sensitivity to *tension* and preference for more *vertexes* and greater *distance*—i.e., spikier shapes. Higher scores in openness to experience were linked to an enhanced ability to discern minute differences in *tension* and preferring more *vertexes*. And greater need for cognition was linked to an enhanced ability to perceive minute *tension* differences, to perceiving contours with more *vertexes*, greater *distance* and lower *tension* as more curved or less angular, and to liking more figures with lower *tension*, suggesting that higher preference for cognitive challenge was linked to a greater perceptual ability and promoted a consistent use of *tension* across evaluations, in the sense that lower *tension* was deemed more curved and liked more. Taken together, the significant effects seem to accentuate the general trends, confirming our expectations. Plausible explanations are that greater interest and experience in visual art, openness to experience, and preference for cognitive challenge lead to boosted sensitivity, understood as enhanced responsiveness to geometric features and general perceptual ability, although the specific effects vary for each trait and geometric feature. More specifically, having greater exposure to art may sensitize viewers to more unusual visual properties—not only gentle, curved ones, but also potentially scary, spiky ones—, openness to experience likely facilitates engagement with a broader range of visual stimuli, and need for cognition entails stronger interest for and attention to detail—linked to an enhanced perception and appreciation of sinuous contours.

As for our chief interest in this study, the implications for the *curvature effect* are worth detailed consideration. The impact of art experience and need for cognition on hedonic sensitivity to *tension* seemed to enhance the *curvature effect*. That is, they made *tension* more relevant for both perceptual and hedonic evaluations, accentuating the *curvature effect* and, likely, the impact of perceptual ratings on the hedonic ones. More data are required to test this hypothetical effect. In contrast, a preference for more *vertexes* and greater *distance*—i.e., more star-like shapes—lacks clear meaning for the *curvature effect*, let alone its intensification. It seems plausible that a preference for more complex figures associated with higher scores in these traits would account for such effects (Clemente et al., 2022a, under review). Further research is required to test the specific role of each geometric feature in the link between perceptual and hedonic evaluations of contour and the contribution of individual traits to those relationships.

General Discussion

This research's primary and overarching goal was to investigate the *curvature effect*: to understand its underlying psychological mechanisms and the factors influencing them. The first step was defining the theoretical construct to which the phenomenon alludes (Corradi & Munar, 2020): *contour* refers here to the degree of curviness. This aligns with the characterisation of contour as variations in concavity or convexity of a figure's profile (Schmidtmann et al., 2015) and with categorical manipulations in the literature (e.g., Bertamini et al., 2016) but goes further in specifying the parameters responsible for such variations along a continuum. We characterised visual contour as a function of three geometric features manipulated systematically and continuously: *vertexes*, *distance* and *tension*. To the best of our knowledge, the open-source ViCo stimulus set and generative tool are the first to manipulate visual contour continuously and multidimensionally. However, beyond laying out the question and the tools to investigate it, this research also provides some revealing evidence about the nature of the *curvature effect*, posing new questions and advancing the understanding of contour perception and appreciation. We shall detail them in the remaining of this section.

Framing the *curvature effect*

How a contour is perceptually identified according to its visual features still requires further investigation, especially considering that those manipulated here conflate in their extreme theoretical values—e.g. infinite *vertexes* or zero *distance* define a curve of minimal *tension*: a circumference. However, the results suggest that the geometric features considered in this study affect contour perception and appreciation at the present scale (spatial frequency) and experimental setting (involving a typical viewing distance of about 50 cm). Every geometric feature accounted for unique and shared proportion of the variance in perceptual and hedonic ratings. That is, they significantly influenced perceived curviness and angularity and how much participants liked the figures separately and in interaction, even when excluding stimuli with $d = 0.1$. Crucially, the parameters manipulated weighted differently to characterise contour and shape. Therefore, future research on contour perception and appreciation ought to factor in or control these effects.

Most remarkably for our interests in this research, the *curvature effect* was restricted to particular configurations of *vertexes*, *distance* and *tension.* When controlling for *vertexes* and *distance*, manipulating *tension* continuously and using binary comparisons (i.e., the method of constant stimuli), preference for lower *tension*—or higher curviness, as interpreted in the literature (e.g., Bar & Neta, 2006; Bertamini et al., 2016; Corradi et al., 2020)—vanished. In other words, the *curvature effect* was unsupported under these conditions.

Perceptual mechanisms explaining the *curvature effect*

Perception and appreciation of sensory objects are fundamental cognitive processes, crucial for survival and presumably interrelated. However, such relations are not fully understood. In the case of contour, curved figures are more easily detected and processed (Bertamini et al., 2019; Yue et al., 2020), which might explain the *curvature effect*, or why most people seem to prefer curved objects. The results of this research offer mixed evidence regarding this hypothesis.

On the one hand, perceptual evaluations significantly predicted hedonic evaluations moderated by shape: The *curvature effect* only emerged when discarding stimuli with d = 0.1, although medium contours tended to be the least liked. Including all shapes (i.e., also with d = 0.1) reverted the overall trend. As pointed out above, the *curvature effect* was mainly driven by variations in *tension* linked to (and plausibly mediated by) perceptual contour representations. However, whereas most participants tended to like more figures with lower *tension* and were consistent in how they used this feature in their perceptual and hedonic evaluations, *tension* was not the primary determinant of liking, which puts into question the nature of the *curvature effect*. Furthermore, the *curvature effect* was limited to independent evaluations (Study 1), but not comparisons (Study 2) of figures varying in *vertexes*, *distance* and *tension* with similar shapes, that is, to contours with alike and sufficiently pronounced alternations of concavities and convexities.

On the other hand, the participants tended to prefer contours with median *tension* regardless of their general perceptual sensitivity (*d*')—i.e., their ability to detect and correctly categorise minute differences in *tension* (Study 2). Apart from suggesting a (higher-level) dissociation between perceptual and hedonic comparisons, this finding indicates that this (lower-level) perceptual ability might not be necessary nor sufficient to define contour preferences.

Testing the *curvature effect* at the group and individual levels

Like most psychological phenomena, the *curvature effect* has been almost exclusively studied and established by averaging across participants (e.g., Bertamini et al., 2016; Palumbo et al., 2015). As a matter of fact, common limitations in the empirical aesthetics literature stem from neglecting individual differences (Clemente, 2022; Güçlütürk et al., 2016). Indeed, investigating how and why individuals behave is crucial to understanding general behavioural mechanisms. Therefore, to ascertain whether the *curvature effect* is genuine and reflects a psychologically meaningful phenomenon, it must be tested at the individual level. To that end, we examined individual sensitivities, defined as individual responsiveness to specific features when evaluating an object (Clemente, 2022; Corradi et al., 2020). This approach allowed us to inspect and compare how people used the geometric features of interest when evaluating a figure perceptually and hedonically, individually and collectively.

At the group level, the results were mixed: On the one hand, as discussed above, the *curvature effect* vanished when controlling for *distance* and *vertexes* in binary comparisons against the median *tension* (Study 2). On the other hand, the results confirm the *curvature effect* when using continuous ratings, manipulating *tension* continuously and accounting for individual variability per participant and stimulus (Study 1). However, some caveats are worth noting: Overall, liking increased for more *vertexes*, greater *distance* and lower *tension*.

That is, overall, participants liked more star-like but smoother contours, which would count as evidence for the *curvature effect* driven by *tension*. However, *tension* was *not* the main predictor of hedonic ratings. It was the main predictor of perceptual ratings in interaction with *vertexes* and only when excluding stimuli with d = 0. *Tension* was, indeed, the weakest predictor of liking, which was mainly driven by *vertexes* and *distance*, mutually enhanced even when excluding stimuli with d = 0.1—i.e., when removing shape differences. This questions the usefulness of contrasting *tension* variants, which is the common approach in the literature (e.g., Bertamini et al., 2016; Bar & Neta, 2006; Corradi et al., 2020). The results point again to the multidimensionality of contour and the distinct relevance of each feature when evaluating perceptually and hedonically. This led us to investigate perceptual and hedonic sensitivities as measures of the extent to which individual perceptual and hedonic evaluations relied on each geometric feature.

At the individual level, we found wide individual variability in how these features affected perceptual and hedonic ratings: Whereas most people deemed figures with fewer *vertexes*, smaller *distance* and lower *tension* as more curved (or less angular), some found them indicative of higher angularity (or lower curviness). As for the *curvature effect*, whereas most participants tended to prefer greater *distance*, more *vertexes* and lower *tension*, some were indifferent to these features, and others showed the opposite tendency. Inspecting individual sensitivities enabled investigating the roles of the manipulated stimulus properties on perceptual and hedonic evaluations. Only when excluding stimuli with d = 0.1, we found a general positive association between hedonic and perceptual sensitivities to *tension*, which was relevant for perceived contour but not so much for liking. Thus, when relying on this feature in continuous manipulations and independent evaluations (Study 1), perceptual and hedonic evaluations tended to converge, likely reflecting an internal curviness reference and a bias toward preferring what is categorised as more curved. This hypothesis needs further testing in purposely controlled settings.

Considering the complex relations between geometric features and perceptual and hedonic evaluations, the *curvature effect* is by no means universal but might result from converging combinations of how each individual uses each geometric feature for each evaluative judgment in particular settings (Study 1). In other words, it may somehow reflect a statistical artefact fruit from aggregating different evaluations by different individuals. Further research is required to test this possibility. Either way, the results add to a growing pool of evidence for the central relevance of individual differences in evaluative judgments (Clemente, 2022; Clemente et al., 2021, 2022a, 2022b; Corradi et al., 2020; Güçlütürk et al., 2016; Spehar, Walker & Taylor, 2016) and extend these claims to perceptual evaluations of visual contour.

Contextualising the *curvature effect*

Personal and contextual factors essential to understanding the *curvature effect* are usually neglected or not sufficiently addressed in the literature (Clemente, 2022; Corradi & Munar, 2020). Here, we focus on the influence of individual traits potentially linked to visual preference (Study 4) and the impact of experimental manipulations (Studies 1 and 2).

Individual traits explaining the *curvature effect.*

In light of the results discussed above, the *curvature effect* seems to be bounded to particular contexts (see Studies 1–3). Therefore, the impact of individual traits would also be contingent on such contexts. In any case, it seems to reflect a preference for contours with lower *tension*, which appears to be enhanced by greater art experience and need for cognition (Study 4). However, the interplay between contour and shape (Study 1) complicates the picture with a plausible interaction between preference for curviness and preference for complexity (Study 3), with the individual traits of interest enhancing preference for curved contours and more complex shapes (Study 4). Such putative interplay precludes an interpretation of the *curvature effect* in terms of threat. Further research is required to examine the relationships between contour and shape, their characterising geometric features and individual traits like those in the present research.

Experimental and contextual factors explaining the *curvature effect*.

We found compelling evidence for the impact of the experimental task—i.e., using continuous ratings (Study 1) vs binary comparisons (Study 2) of stimuli varying continuously in *tension* with stimuli with median *tension* while controlling for *vertexes* and *distance*—and the experimental *condition*—i.e., asking about curviness vs angularity. We discuss them below.

First, when comparing continuous variations in *tension* against the median *tension*, the *curvature effect* disappeared (Study 2). This was true even when excluding trials in which the reference was preferred: participants' preference still tended towards median *tension* and was essentially flat when departing from this value. In other words, the *curvature effect* was not robust to binary comparisons of a spectrum of *tension* levels with the median, as most participants preferred the latter regardless of differences in *vertexes* and *distance* (i.e., differences in shape). Thus, the *curvature effect* seems sensitive to the experimental paradigm (Corradi & Munar, 2020), which suggests caution when generalising effects and attributing them psychological entity. This contextual effect is particularly remarkable and warns about the role of the experimental paradigm and its biasing potential. Further research is required to ascertain whether the *curvature effect* would emerge from the comparison between the angular extreme with anything else—explaining the findings in previous research (e.g., Bertamini et al., 2016; Bar & Neta, 2006; Clemente et al., 2021; Corradi et al., 2020)—or people would still prefer lower over medium *tension* (i.e., greater curviness). According to the results, we hypothesise that people would prefer contours with medium over high (angular) and low (curved) *tension*. In addition, it is necessary to disentangle the influence of *tension* levels from that of the binary comparison. That is, future studies ought to test whether people would prefer contours with median *tension* in evaluations of single stimuli and binary comparisons of categorical *tension* levels (e.g., curved vs medium, medium vs angled).

Second, the effects of *condition* suggest a distinct mindset enabling participants to be more accurate in detecting minute differences in *tension* when asked about angularity (Study 2). This explains a tendency to like more figures with not only smaller *distance* but also fewer *vertexes*, perhaps because these allow for better accounts of differences in *tension* (Study 3). Nevertheless, the influences of openness to experience and need for cognition complicate the picture, perhaps moderating the aforementioned effects (Study 4). Further investigation is needed to clarify the nature of these relationships.

Third, the impact of response *laterality* in interaction with *vertexes* and *tension* in Study 1 may stem from a priming effect of the preceding hedonic task, in which liking increased toward the right end of the slider. Research shows a general tendency for curviness to entail more positive and pleasant associations and, conversely, angularity to be associated with more dangerous objects and to elicit more defensive affective responses (Bar & Neta, 2007; Bertamini et al., 2016; Palumbo et al., 2015). Thus, it makes sense that the placement of curviness ratings in the same direction as liking was deemed somehow more congruent, intensifying the effects of *tension*. Notwithstanding, three-way interactions like this should be cautiously considered, and further research is needed to corroborate or counter these findings.

Implications for the appreciation of ecological stimuli

Scientific research oftentimes involves a trade-off between experimental control and ecological validity. We favoured the first by using abstract, parametrised stimuli to disentangle an apparently well-established effect. This allowed us to prevent, or at least minimise, the influence of potentially confounding factors and, hence, to focus on the central claim of the *curvature effect*. However, this also entailed an obvious limitation in ecological validity and points to the need for a conceptual link between our findings involving contour and other factors that impact our assessments of everyday objects. For instance, research has shown the relevance of familiarity, typicality, functionality, adequateness, Zeitgeist (Blijlevens et al., 2012; Carbon, 2010; Leder & Carbon, 2005) and other factors in contour appreciation. In most cases, these factors override the effects of contour per se and uncover fundamental individual differences. Therefore, to understand whether and to what extent there is a genuine *curvature effect* and look into its psychological underpinnings, we found it necessary as a first step to distil contour preference from other constructs like shape and factors like those mentioned above in a very controlled setting. The next step will be to use a more naturalistic approach to investigate how those factors and constructs interact regarding everyday objects.

In this vein, a fundamental outcome of the present work is that investigating the appreciation of everyday objects or scenes may not be reducible to inspecting preference for curvature as a global construct. In addition, we have shown that the task, the referential framework and individual differences are crucial to understanding hedonic evaluation even when the construct is well delimited and parametrised. These findings align with a view of hedonic evaluation (i.e., appreciation) as resulting from the integrated processing of sensory information considering personal and contextual factors (Skov, 2019).

Implications for contour appreciation in other sensory modalities

Although research on contour appreciation (and the *curvature effect*) has primarily focused on the visual modality, contour is also a prominent factor affecting hedonic evaluation in other sensory modalities. On the one hand, haptics research has found hints of a similar *curvature effect*, with individual exceptions and an overriding impact of contextual cues and ergonomic aspects (Jakesch & Carbon, 2011; Soranzo, Petrelli, Ciolfi & Reidy, 2018), in line with our results. On the other hand, contour is an essential aspect of speech and music. Whereas prosody is vital for oral communication, it is even more crucial for music. Research indicates that speech perception is hampered by the degradation of temporal information, whereas melodic perception is hampered only by spectral degradation (Albouy, Benjamin, Morillon & Zatorre, 2020). Indeed, pitch intervals and their directions are fundamental aspects of a melody. As such, and analogous to, at least, the *vertexes* and *distance* dimensions in our stimuli in the visual domain, Clemente and colleagues defined melodic contour and investigated the hedonic evaluation of contour in music (Clemente et al., 2022b) and across the visual and music domains (Clemente et al., 2021, 2022a). These studies also unveiled a general preference for smoother musical contours and, most interestingly, an association between hedonic (or aesthetic) sensitivities (Clemente et al., 2021) and between perceived-valence sensitivities (Clemente et al., 2022a) to musical and visual contour.

Taken together, these general trends in the visual, haptic and musical domains suggest a potentially multimodal general preference for contour, genuine to some extent at the individual level across the visual and music domains (Clemente et al., 2021). However, the present research emphasises the relevance of contour characterisation and unveils the limitations of such a general preference for smooth contours. It is reasonable to anticipate that a similar approach in other domains might lead to new and plausibly more complex findings regarding contour preference. For instance, the visual stimuli used in Clemente and colleagues' series of studies followed Bertamini et al.'s (2016) design and, therefore, suffer from the limitations already pointed out: These stimuli consist of dichotomous *tension* variations (curved vs angled) over similar *vertexes* and *distance* combinations, whereas melodic contour was a continuous dimension. Additionally, pitch is essentially a discrete, categorical dimension in Western tonal music like that of the stimuli in the mentioned studies. To parallel our *tension* dimension, a continuous pitch dimension would be required. Moreover, the extent to which the psychological mechanisms of melodic and visual contour processing are common remains to be explored. In conclusion, further research is necessary to elucidate the genuineness of contour preference across domains and its psychological underpinnings.

Limitations and future work

Besides the generalisability issues discussed in previous sections, the first limitation of this study is that the effect sizes were often small or very small. This precludes drawing strong conclusions and points to the need for further investigation.

In addition, the order of paradigms and tasks was invariable, which prevented us from testing their influence and avoiding the priming effects of hedonic evaluations on perceptual evaluations (Study 1) and vice versa (Study 2) discussed above. Future studies should directly examine task order effects or, at least, control them through counterbalance or randomisation.

Also, this study involved experimental manipulations between participants (Study 2) due to the duration of the experimental session. Therefore, future research should test all experimental conditions within participants.

Ideally, each stimulus feature should be continuously manipulated and tested while controlling for the other features. Additionally, the spatial configuration of the vertexes exerted a notable influence on perceptual and hedonic ratings, differentiating two shape categories. Future research ought to account for this and test its specific contribution. Besides, it is crucial to replicate our findings with other stimulus kinds—particularly naturalistic stimuli—and implement manipulations of different features—departing from rounded vs star-like shapes.

It is worth noting that we intended our sample to be representative of the general population. Therefore, we neither purposely included experts in visual art or design nor aimed for wide variability in the assessed individual traits. Whereas this approach entails higher ecological validity and thus facilitates the generalisability of the results, the variation captured in these traits might not be sufficient to draw strong claims about their effects. We did not test the effects of expertise for similar reasons, although expecting effects on perceptual and hedonic sensitivities seems reasonable (Silvia & Barona, 2009). Further research with larger samples including experts will elucidate the impact of these traits and expertise on perceptual and hedonic sensitivities.

Finally, the experiment was conducted online. Even if we customarily checked performance, prescreened the participants under strict criteria and adjusted the sample size, the experimental control is inherently lower than in lab settings, and online data are typically noisier. Thus, lab-based replications are highly desirable.

Conclusion

The *curvature effect* is not as robust and straightforward as the rich literature on the topic might suggest (e.g., Palumbo et al., 2015; Bertamini et al., 2016; Gómez-Puerto et al., 2018; Corradi et al., 2020; Corradi & Munar, 2020). On the contrary, this research presents a complex picture that is not reducible to a monotonous relationship and prompts critical reflections on past research, advances the understanding of contour perception and appreciation and poses new questions and advice for future research. First, perceptual and hedonic evaluations relied on multiple geometric features (e.g., *vertexes*, *distance* and *tension*) defining contour and shape, each of particular relevance for each individual and evaluation kind. Second and crucially, the *curvature effect* was limited to particular settings involving continuous or categorical ratings and binary or continuous manipulations of *tension* —i.e., presenting participants with more or less curved or angular versions of the same basic shape. Third, in addition to the experimental conditions, domain-specific, personality and cognitive-preference traits moderated the impact of each feature on perceptual and hedonic evaluations, emphasising the relevance of individual differences in perception and appreciation.

Our findings highlight the importance and usefulness of considering the complex relations between stimulus features and perceptual and hedonic evaluations at the group and individual levels: First, precisely defining and characterising the construct of interest allows to inquire into the nature of psychological categories and their evaluative correlates. Second, systematically inspecting the impact of specific object features on perceptual and hedonic evaluations facilitates the investigation of the underlying mechanisms and how they relate.

Third, accounting for individual differences and approaching the data at the individual level enables to examine the genuineness and psychological nature of group-level effects. Finally, accounting for personal and contextual factors provides a means for testing established phenomena in a new light and advancing knowledge on human cognition and behaviour.

References

Albouy, P., Benjamin, L., Morillon, B., & Zatorre, R. J. (2020). Distinct sensitivity to spectrotemporal modulation supports brain asymmetry for speech and melody. *Science, 367*(6481), 1043–1047. https://doi.org/10.1126/science.aaz3468

Bar, M., & Neta, M. (2006). Humans prefer curved visual objects. *Psychological Science, 17*, 645–648. https://doi.org/10.1111/j.1467-9280.2006.01759.x

Bar, M., & Neta, M. (2007). Visual elements of subjective preference modulate amygdala activation. *Neuropsychologia, 45*, 2191–2200. https://doi.org/10.1016/j.neuropsychologia.2007.03.008

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language, 68*(3), 255–278. https://doi.org/10.1016/j.jml.2012.11.001

Bartoń, K. (2020). MuMIn: Multi-Model Inference. R package version 1.43.17. https://CRAN.R-project.org/package=MuMIn

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67*(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Ben-Shachar, M., Makowski, D., Lüdecke, D. (2020). Compute and interpret indices of effect size. *CRAN. R package*, https://github.com/easystats/effectsize. Accessed 11 January 2021

Bertamini, M. (2001). The importance of being convex: An advantage for convexity when evaluating position. *Perception, 30*(11), 1295–1310. https://doi.org/10.1068/p3197

Bertamini, M. (2008). Detection of convexity and concavity in context. *Journal of Experimental Psychology: Human Perception and Performance, 34*(4), 775–789. https://doi.org/10.1037/0096-1523.34.4.775

Bertamini, M., Palumbo, L., Gheorghes, T. N., & Galatsidas, M. (2016). Do observers like curvature or do they dislike angularity?. *British Journal of Psychology, 107*(1), 154–178. https://doi.org/10.1111/bjop.12132

Bertamini, M., & Wagemans, J. (2012). Processing convexity and concavity along a 2-D contour: figure–ground, structural shape, and attention. *Psychonomic Bulletin & Review, 20*(2), 191–207. https://doi.org/10.3758/s13423-012-0347-2

Biederman, I. (1987). Recognition-by-components: a theory of human image understanding. *Psychological Review, 94*(2), 115.

Blijlevens, J., Carbon, C. C., Mugge, R., & Schoormans, J. P. (2012). Aesthetic appraisal of product designs: Independent effects of typicality and arousal. *British Journal of Psychology, 103*(1), 44-57. https://doi.org/10.1111/j.2044-8295.2011.02038.x

Cacioppo, J. T., & Petty, R. E. (1982). The need for cognition. *Journal of Personality and Social Psychology, 42*(1), 116. https://doi.org/10.1037/0022-3514.42.1.116

Cacioppo, J. T., Petty, R. E., & Feng Kao, C. (1984). The efficient assessment of need for cognition. *Journal of Personality Assessment, 48*(3), 306–307. https://doi.org/10.1207/s15327752jpa4803_13

Caplovitz, G. P., & Tse, P. U. (2007). V3A processes contour curvature as a trackable feature for the perception of rotational motion. *Cerebral Cortex, 17*(5), 1179–1189. https://doi.org/10.1093/cercor/bhl029

Carbon, C. C. (2010). The cycle of preference: Long-term dynamics of aesthetic appreciation. *Acta Psychologica, 134*(2), 233–244. https://doi.org/10.1016/j.actpsy.2010.02.004

Chamorro-Premuzic, T., Reimers, S., Hsu, A., & Ahmetoglu, G. (2009). Who art thou? Personality predictors of artistic preferences in a large UK sample: The importance of openness. *British Journal of Psychology, 100*, 501–516. https://doi.org/10.1348/000712608X366867

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

Che, J., Sun, X., Gallardo, V., & Nadal, M. (2018). Cross-cultural empirical aesthetics. *Progress in Brain Research, 237*, 77–103. https://doi.org/10.1016/bs.pbr.2018.03.002

Chenier, T., & Winkielman, P. (2009). The origins of aesthetic pleasure: Processing fluency and affect in judgment, body, and the brain. *Neuroaesthetics*, 275–289. https://doi.org/10.4324/9781315224091-14

Clemente, A. (2022). Aesthetic sensitivity: Origin and development. In *The Routledge International Handbook of Neuroaesthetics* (pp. 240–253). Routledge. https://doi.org/10.4324/9781003008675-13

Clemente, A., Friberg, A., & Holzapfel, A. (2022a). Relations between perceived affect and liking for melodies and visual designs. *Emotion*. Advance online publication. https://doi.org/10.1037/emo0001141

Clemente, A., Kaplan, T. M., & Pearce, M. T. (under review). Unraveling musical pleasure: The role of stimulus properties and behavioural evaluations on liking for melodies.

Clemente, A., Pearce, M. T., & Nadal, M. (2022b). Musical aesthetic sensitivity. P*sychology of Aesthetics, Creativity, and the Arts*. Advance online publication. https://doi.org/10.1037/aca0000381

Clemente, A., Pearce, M. T., Skov, M., & Nadal, M. (2021). Evaluative judgment across domains: Liking balance, contour, symmetry and complexity in melodies and visual designs. *Brain and Cognition, 151*, 105729. https://doi.org/10.1016/j.bandc.2021.105729

Coburn, A., Vartanian, O., Kenett, Y. N., Nadal, M., Hartung, F., Hayn-Leichsenring, G., ... & Chatterjee, A. (2020). Psychological and neural responses to architectural interiors. *Cortex, 126*, 217–241. https://doi.org/10.1016/j.cortex.2020.01.009

Corradi, G., Belman, M., Currò, T., Chuquichambi, E. G., Rey, C., & Nadal, M. (2019). Aesthetic sensitivity to curvature in real objects and abstract designs. *Acta Psychologica, 197*, 124–130. https://doi.org/10.1016/j.actpsy.2019.05.012

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

Corradi, G. & Munar, E. (2020). The curvature effect. In Nadal, M. & Vartanian, O. (Eds.) *The Oxford Handbook of Empirical Aesthetics*. https://doi.org/10.1093/oxfordhb/9780198824350.013.24

Cotter, K. N., Silvia, P. J., Bertamini, M., Palumbo, L., & Vartanian, O. (2017). Curve appeal: Exploring individual differences in preference for curved versus angular objects. *I-Perception, 8*(2), 1–17. https://doi.org/10.1177/2041669517693023

De Winter, J., & Wagemans, J. (2008). Perceptual saliency of points along the contour of everyday objects: A large-scale study. *Perception and Psychophysics, 70*(1), 50–64. https://doi.org/10.3758/pp.70.1.50

Fantz, R. L. (1961). The origin of form perception. *Scientific American, 204*(5), 66–73. https://www.jstor.org/stable/24937459

Fechner, G. T. (1866). Das Associationsprincip in der Aesthetik [The aesthetic association principle]. *Zeitschrift für bildende Kunst, 1*(1), 179–191.

Friedenberg, J.; Bertamini, M. (2015). Aesthetic preference for polygon shape. *Empirical Studies of the Arts, 33*(2), 144–160. https://doi.org/10.1177/0276237415594708

Furnham, A., & Chamorro-Premuzic, T. (2004). Personality, intelligence, and art. *Personality and Individual Differences, 36*, 705–715. https://doi.org/10.1016/S0191-8869(03)00128-4

Furnham, A., & Walker, J. (2001). Personality and judgements of abstract, pop art, and representational paintings. *European Journal of Personality, 15*(1), 57–72. https://doi.org/10.1002/per.340

Gignac, G. E., & Szodorai, E. T. (2016). Effect size guidelines for individual differences researchers. *Personality and Individual Differences, 102*, 74–78. https://doi.org/10.1016/j.paid.2016.06.069

Gollwitzer, A., & Clark, M. S. (2019). Anxious attachment as an antecedent of people's aversion towards pattern deviancy. *European Journal of Social Psychology*, *49*, 1206–1222. https://doi.org/10.1002/ejsp.2565

Gómez-Puerto, G., Munar, E., & Nadal, M. (2016). Preference for curvature: A historical and conceptual framework. *Frontiers in Human Neuroscience, 9*, 712. https://doi.org/10.3389/fnhum.2015.00712

Gómez-Puerto, G., Rosselló, J., Corradi, G., Acedo-Carmona, C., Munar, E., & Nadal, M. (2018). Preference for curved contours across cultures. *Psychology of Aesthetics, Creativity, and the Arts, 12*(4), 432–439. https://doi.org/10.1037/aca0000135

Gosling, S. D., Rentfrow, P. J., & Swann Jr, W. B. (2003). A very brief measure of the Big-Five personality domains. *Journal of Research in personality, 37*(6), 504–528. https://doi.org/10.1016/S0092-6566(03)00046-1

Güçlütürk, Y., Jacobs, R. H. A. H., & Lier, R. van. (2016). Liking versus complexity: Decomposing the inverted U-curve. *Frontiers in Human Neuroscience, 10*. https://doi.org/10.3389/fnhum.2016.00112

Hevner, K. (1935). Experimental studies of the affective value of colors and lines. *Journal of Applied Psychology, 19*(4), 385–398. https://doi.org/10.1037/h0055538

Hox, J. J., Moerbeek, M., & van de Schoot, R. (2010). *Multilevel Analysis: Techniques and Applications*. Routledge.

Hutmacher, F. (2019). Why is there so much more research on vision than on any other sensory modality? *Frontiers in Psychology, 10*. https://doi.org/10.3389/fpsyg.2019.02246

Jadva, V., Hines, M., & Golombok, S. (2010). Infants' preferences for toys, colors, and shapes: Sex differences and similarities. *Archives of Sexual Behavior, 39*(6), 1261–1273. https://doi.org/10.1007/s10508-010-9618-z

Jakesch, M., & Carbon, C. C. (2011). Humans prefer curved objects on basis of haptic evaluation, *Perception, 40*, 219–219. https://doi.org/10.1177/03010066110400S102

Judd, C. M., Westfall, J., & Kenny, D. A. (2016). Experiments with more than one random factor: Designs, analytic models, and statistical power. *Annual Review of Psychology.* https://doi.org/10.1146/annurev-psych-122414-033702

Kanizsa, G. (1976). Convexity and symmetry in figure-ground organization. *Vision and Artifact.*

Koffka, K. (1935). *Principles of Gestalt Psychology*. Harcourt, Brace.

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. (2017). lmerTest package: Tests in linear mixed effects models. *Journal of Statistical Software, 82*(1), 1–26. https://doi.org/10.18637/jss.v082.i13

Landy, J. F., & Piazza, J. (2019). Reevaluating moral disgust: Sensitivity to many affective states predicts extremity in many hedonic evaluations. *Social Psychological and Personality Science, 10*, 211–219. https://doi.org/10.1177/1948550617736110

Le, A. T., Payne, J., Clarke, C., Kelly, M. A., Prudenziati, F., Armsby, E., ... & Wilkins, A. J. (2017). Discomfort from urban scenes: Metabolic consequences. *Landscape and Urban Planning, 160*, 61–68. https://doi.org/10.1016/j.landurbplan.2016.12.003

Leder, H., & Carbon, C. C. (2005). Dimensions in appreciation of car interior design. *Applied Cognitive Psychology: The Official Journal of the Society for Applied Research in Memory and Cognition, 19*(5), 603–618. https://doi.org/10.1002/acp.1088

Lenth, R. V. (2021). 'Emmeans': Estimated marginal means, aka least-squares means. R package version 1.5.4. https://CRAN.R-project.org/package=emmeans

Luke, S. G. (2017). Evaluating significance in linear mixed-effects models in R. *Behavior Research Methods, 49*, 1494–1502. https://doi.org/10.3758/s13428-016-0809-y

Lundholm, H. (1921). The affective tone of lines: Experimental researches. *Psychological Review, 28*(1), 43–60. https://doi.org/10.1037/h0072647

Mach, E. (1914). *The Analysis of Sensations*. Open Court Publishing Company.

Macmillan, N. A., & Creelman, C. D. (2005). *Detection Theory: A User's Guide* (2nd ed.). Lawrence Erlbaum Associates Publishers.

Makowski, D. (2018). The 'psycho' package: An efficient and publishing-oriented workflow for psychological science. *Journal of Open Source Software, 3*(22), 470. https://doi.org/10.21105/joss.00470

Munar, E., Gómez-Puerto, G., Call, J., & Nadal, M. (2015). Common visual preference for curved contours in humans and great apes. *PloS One, 10*(11), e0141106. https://doi.org/10.1371/journal.pone.0141106

Nadal, M., Munar, E., Marty, G., & Cela-Conde C. J. (2010). Visual complexity and beauty appreciation: Explaining the divergence of results. *Empirical Studies of the Arts, 28*, 173–191. https://doi.org/10.2190/EM.28.2.d

Ortlieb, S. A., Kügel, W. A., & Carbon, C. C. (2020). Fechner (1866): The aesthetic association principle: A commented translation. *i-Perception, 11*(3), 2041669520920309. https://doi.org/10.1177/2041669520920309

Palumbo, L., & Bertamini, M. (2016). The curvature effect: A comparison between preference tasks. *Empirical Studies of the Arts, 34*(1), 35–52. https://doi.org/10.1177/0276237415621185

Palumbo, L., Ruta, N., & Bertamini, M. (2015). Comparing angular and curved shapes in terms of implicit associations and approach/avoidance responses. *PLoS One, 10*(10), e0140043. https://doi.org/10.1371/journal.pone.0140043

Penacchio, O., & Wilkins, A. J. (2015). Visual discomfort and the spatial distribution of Fourier energy. *Vision Research, 108*, 1–7. https://doi.org/10.1016/j.visres.2014.12.013

Pessiglione, M., & Lebreton, M. (2015). From the reward circuit to the valuation system: How the brain motivates behavior. *Handbook of Biobehavioral Approaches to Self-Regulation*, 157–173. https://doi.org/10.1007/978-1-4939-1236-0_11

Powell, G., Meredith, Z., McMillin, R., & Freeman, T. C. (2016). Bayesian models of individual differences: Combining autistic traits and sensory thresholds to predict motion perception. *Psychological Science, 27*(12), 1562–1572. https://doi.org/10.1177/0956797616665351

R Core Team (2021). R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. http://www.R-project.org. Accessed 11 January 2021.

Rangel, A., Camerer, C., & Montague, P. R. (2008). A framework for studying the neurobiology of value-based decision making. *Nature Reviews Neuroscience, 9*(7), 545–556. https://doi.org/10.1038/nrn2357

Rawlings, D. (2003). Personality correlates of liking for 'unpleasant'paintings and photographs. *Personality and Individual Differences, 34*(3), 395–410. https://doi.org/10.1016/S0191-8869(02)00062-4

Rawlings, D., Barrantes i Vidal, N., & Furnham, A. (2000). Personality and aesthetic preference in Spain and England: Two studies relating sensation seeking and openness to experience to liking for paintings and music. *European Journal of Personality, 14*(6), 553–576. https://doi.org/10.1002/1099-0984(200011/12)14:6<553::AID-PER384>3.0.CO;2-H

Reber, R. (2012). Processing fluency, aesthetic pleasure, and culturally shared taste. *Aesthetic Science: Connecting Mind, Brain, and Experience*, 223–249. https://doi.org/10.1093/acprof:oso/9780199732142.003.0055

Reber, R., Schwarz, N., & Winkielman, P. (2004). Processing Fluency and Aesthetic Pleasure: Is Beauty in the Perceiver's Processing Experience? *Personality and Social Psychology Review, 8*(4), 364–382. https://doi.org/10.1207/s15327957pspr0804_3

Ruff, H. A., & Birch, H. G. (1974). Infant visual fixation: The effect of concentricity, curvilinearity, and number of directions. *Journal of Experimental Child Psychology, 17*(3), 460–473. https://doi.org/10.1016/0022-0965(74)90056-3

Ruta, N., Mastandrea, S., Penacchio, O., Lamaddalena, S., & Bove, G. (2019). A comparison between preference evaluations of curvature and sharpness in architectural façades. *Architectural Science Review, 62*(2), 171–181. https://doi.org/10.1080/00038628.2018.1558393

Ruta, N., Vañó, J., Pepperell, R., Corradi, G. B., Chuquichambi, E. G., Rey, C., & Munar, E. (2021). Preference for paintings is also affected by curvature. *Psychology of Aesthetics, Creativity, and the Arts.* Advance online publication. https://doi.org/10.1037/aca0000395

Sauter, M., Draschkow, D., & Mack, W. (2020). Building, hosting and recruiting: A brief introduction to running behavioral experiments online. *Brain Sciences, 10*(4), 251. https://doi.org/10.3390/brainsci10040251

Schmidtmann, G., Jennings, B. J., & Kingdom, F. A. (2015). Shape recognition: convexities, concavities and things in between. *Scientific Reports, 5*(1), 1–11. https://doi.org/10.1167/15.12.242

Silvia, P. J., & Barona, C. M. (2009). Do people prefer curved objects? Angularity, expertise, and aesthetic preference. *Empirical Studies of the Arts, 27*(1), 25–42. https://doi.org/10.2190/EM.27.1.b

Simpson, W. A. (1988). The method of constant stimuli is efficient. *Perception and Psychophysics, 44*(5), 433–436. https://doi.org/10.3758/bf03210427

Skewes, J. C., Jegindø, E.-M., Gebauer, L. (2015). Perceptual inference and autistic traits. *Autism, 19*, 301–307. https://doi.org/10.1177/1362361313519872

Skov, M. (2019). Aesthetic appreciation: The view from neuroimaging. *Empirical Studies of the Arts, 37*(2), 220–248. https://doi.org/10.1177/0276237419839257

Skov, M. (2020). The neurobiology of sensory valuation. *The Oxford Handbook of Empirical Aesthetics*. https://doi.org/10.1093/oxfordhb/9780198824350.013.7

Skov, M. & Nadal, M. (2021). The nature of beauty: Behavior, cognition, and neurobiology. *Annals of the New York Academy of Sciences, 1488*, 44–55. https://doi.org/10.1111/nyas.14524

Snijders, T. A. B. & Bosker, R. J. (2012). *Multilevel analysis. An introduction to basic and advanced multilevel modeling* (2nd ed.). London: SAGE Publications.

Spehar, B., Walker, N., & Taylor, R. P. (2016). Taxonomy of individual variations in aesthetic responses to fractal patterns. *Frontiers in Human Neuroscience, 10*, 350. https://doi.org/10.3389/fnhum.2016.00350

Soranzo, A., Petrelli, D., Ciolfi, L., & Reidy, J. (2018). On the perceptual aesthetics of interactive objects. *Quarterly Journal of Experimental Psychology, 71*(12), 2586–2602. https://doi.org/10.1177/1747021817749228

Stewart, N., Chandler, J., & Paolacci, G. (2017). Crowdsourcing samples in cognitive science. *Trends in Cognitive Sciences, 21*(10), 736–748. https://doi.org/10.1016/j.tics.2017.06.007

Thaler, L., Schütz, A. C., Goodale, M. A., & Gegenfurtner, K. R. (2013). What is the best fixation target? The effect of target shape on stability of fixational eye movements. *Vision Research, 76*, 31–42. https://doi.org/10.1016/j.visres.2012.10.012

Thompson, P., & Burr, D. (2009). Visual aftereffects. *Current Biology, 19*(1), R11–R14. https://doi.org/10.1016/j.cub.2008.10.014

Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12*(1), 97–136. https://doi.org/10.1016/0010-0285(80)90005-5

Tse, P. U., & Caplovitz, G. P. (2006). Contour discontinuities subserve two types of form analysis that underlie motion processing. *Progress in Brain Research, 154*, 271–292. https://doi.org/10.1016/S0079-6123(06)54015-4

Van Geert, E., & Wagemans, J. (2020). Order, complexity, and aesthetic appreciation. *Psychology of Aesthetics, Creativity, and the Arts, 14*(2), 135–154. https://doi.org/10.1037/aca0000224

Vartanian, O., Navarrete, G., Chatterjee, A., Fich, L. B., Leder, H., Modroño, C., Rostrup, N., Skov, M., Corradi, G., & Nadal, M. (2019). Preference for curvilinear contour in interior architectural spaces: Evidence from experts and nonexperts. *Psychology of Aesthetics, Creativity, and the Arts, 13*(1), 110–116. https://doi.org/10.1037/aca0000150

Wagemans, J. (2018). Perceptual organization. Stevens' *Handbook of Experimental Psychology and Cognitive Neuroscience*, 1–70. https://doi.org/10.1002/9781119170174.epcn218

Wagemans, J. (Ed.). (2015). *The Oxford Handbook of Perceptual Organization*. https://doi.org/10.1093/oxfordhb/9780199686858.001.0001

Wolfe, J. M., Yee, A., & Friedman-Hill, S. R. (1992). Curvature is a basic feature for visual search tasks. *Perception, 21*(4), 465–480. https://doi.org/10.1068/p210465

Yetter, M., Robert, S., Mammarella, G., Richmond, B., Eldridge, M. A., Ungerleider, L. G., & Yue, X. (2021). Curvilinear features are important for animate/inanimate categorization in macaques. *Journal of Vision, 21*(4), 3–3. https://doi.org/10.1167/jov.21.4.3

Yue, X., Robert, S., & Ungerleider, L. G. (2020). Curvature processing in human visual cortical areas. *NeuroImage, 222*, 117295. https://doi.org/10.1016/j.neuroimage.2020.117295

Zaidel, A., Goin-Kochel, R. P., Angelaki, D. E. (2015). Self-motion perception in autism is compromised by visual noise but integrated optimally across multiple senses. *Proceedings of the National Academy of Sciences, USA, 112*, 6461–6466. https://doi.org/10.1073/pnas.1506582112

Appendix: Technical Implementation

All analyses were performed within the R environment for statistical computing, R version 4.1.1 (R Core Team, 2021). For the mixed-effects models, we used the `lmer` function of the 'lme4' package (Bates, Maechler, Bolker & Walker, 2015) and the 'lmerTest' package (Kuznetsova, Brockhoff & Christensen, 2017) 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). For the regressions, we used the `lm` function of the 'stats' R package. To compute *d*', we used the `dprime` function in the 'psycho' package (Makowski, 2018).

In all models, continuous predictors (*distance* and *tension*) were centred (subtracting the variable means) and scaled (dividing by the standard deviations) using the `scale` function in the 'base' R package to allow comparisons between them and with categorical variables. Categorical predictors were coded using the `contrasts` function in the R 'stats' package, set to `contr.sdif` (i.e., based on successive differences). The `emmeans` function from the 'emmeans' R package (Lenth, 2021) confirmed our interpretations of the significant effects of factor variables.

We tested whether removing effects from each model significantly improved the model fit through ANOVA mixed-model likelihood-ratio tests. Otherwise, we preferred the saturated model. For statistically significant differences ($p < .05$), lower Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) indicate a better fit of one model over another.

Effect sizes of each factor in the models were calculated using the `effectsize` function of the 'effectsize' package (Ben-Sachar, Makowski & Lüdecke, 2020), providing

95% CIs. To interpret the effect sizes (Cohen's *d*), we followed Gignac and Szodorai's (2016) recommendations. Marginal (r^2_m) and conditional (r^2_c) coefficients of determination for the (generalized mixed) models were calculated using the `r.squaredGLMM` function of the 'MuMIn' package (Bartoń, 2021).