Universitat de les Illes Balears

DOCTORAL THESIS
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THE PSYCHOLOGICAL BASES OF VISUAL PREFERENCE FOR CURVATURE

Erick Gustavo Chuquichambi Apaza

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Doctoral Programme in *Human Cognition and Evolution*

THE PSYCHOLOGICAL BASES OF VISUAL PREFERENCE FOR CURVATURE

Erick Gustavo Chuquichambi Apaza

Thesis Supervisor: Enric Munar Roca
Thesis Supervisor: Letizia Palumbo
Thesis Tutor: Enric Munar Roca

Doctor by the Universitat de les Illes Balears

Universitat de les Illes Balears

Dr Enric Munar, of the University of the Balearic Islands

I DECLARE:

That the thesis titled *The Psychological Bases of Visual Preference for Curvature*, presented by Erick Gustavo Chuquichambi Apaza to obtain a doctoral degree, has been completed under my supervision and meets the requirements to opt for an International Doctorate.

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

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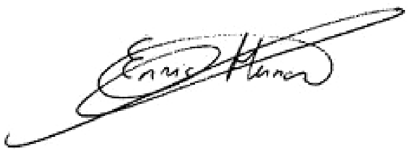

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Universitat de les Illes Balears

Dr Letizia Palumbo, of the Liverpool Hope University

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LIST OF PUBLISHED CONTENT

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Chuquichambi, E.G., Palumbo, L., Rey, C. & Munar, E. (2021). Shape familiarity modulates preference for curvature in drawings of common-use objects. *PeerJ, 9*, e11772. https://doi.org/10.7717/peerj.11772

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Chuquichambi, E.G., Corradi, G.B., Munar, E. & Rosselló-Mir, J. (2021). When symmetric and curved visual contours meet intentional instructions: Hedonic value and preference. *Quarterly Journal of Experimental Psychology, 74*(9), 1525-1541. https://doi.org/10.1177/17470218211021593

JIF: 2.138

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[1]JCR*: Journal Citation Reports
[2]JIF*: Journal Impact Factor

STATEMENT ON OPEN SCIENCE

This Doctoral Thesis is written with TinyTeX (R package version 0.37) —A lightweight, cross-platform, portable, and easy-to-maintain LaTeX distribution based on TeX Live (Xie, 2022; https://github.com/yihui/tinytex).

The materials, data, and code obtained in the publications of this thesis have been made available at the Open Science Framework, following Open Science principles. Feel free to request any additional information or material.

Chuquichambi, Vartanian et al. (2022): https://osf.io/58n23/ (DOI: 10.17605/OSF.IO/58N23).

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DEDICATORY

Today I am getting married to myself! Today is my PhD Viva! Lots of work, lots of joy, some disappointments, and the best experiences and memories of my life. Here is a brief thread.

My journey starts and continues because of the Human Evolution and Cognition group (EvoCog). Specifically, I am very grateful to my supervisor and mentor, Enric Munar. Thank you for everything you have done for me. I firmly believe that this was the best decision of my PhD. I admire you and I am very lucky to have you as my reference. I am also grateful to Marcos, Jaume, and Gisèle. I will always remember how motivated and happy I was when going to your classes (I wanted them to never end!). You believed in me and helped me to challenge myself, especially when I was a recently graduated student. Thank you, Jordi, Juan Tomás, and Toni. Thank you all professors for believing in me, a Bolivian guy obsessed with enthusiasm.

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Thanks to psychology because it helped me to challenge myself and grasp the gist of life. I know myself. I am pretty shy but confident, determined, disciplined, and passionate about life. I have enjoyed every day I have been to the UIB (I still do it after 10 years!). How many pictures did I take here? You are like my house! Thank you to all the people who helped me at the University. You will always be in my heart and memories.

Finally, I congratulate myself, Erick Gustavo! A shy and extremely positive guy who was a bit lost at the university (since 2013!). *But you cannot find yourself if you are not lost!* Remember that everything matters and this doctoral thesis is for us. Dare To Do! Daré Todo!

Erick Gustavo Chuquichambi Apaza

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Live your life, live your life, live your life. Here is my attempt to do so.

THE PSYCHOLOGICAL BASES OF VISUAL PREFERENCE FOR CURVATURE

Abstract

Visual contour affects human-environment interactions. We rely on contour features to categorize, manipulate, and evaluate objects. We prefer objects with curved contours and associate curvature with more positive feelings than sharp-angled contours. This preference is known as the curvature effect, and has been demonstrated between different ages, cultures, and even species. However, the literature has also shown that the effect could be modulated by various contextual and individual difference factors. This dissertation synthesizes the scientific literature on preference for visual curvature and yields new empirical evidence addressing the possible modulator factors of the effect.

In *How universal is preference for visual curvature? A systematic review and meta-analysis*, we show that preference for curvature consists of a reliable and moderate effect in the literature. However, we also show that this preference coexists with substantial heterogeneity variance between studies. This variance is consistent with the moderating effects of factors such as task, stimulus type, presentation time, and expertise. Together, these findings support the idea that the preference for curvature is influenced by factors other than perceptual information.

In *Circles are detected faster than downward-pointing triangles in a speeded response task*, we propose that curved contours capture attention and are processed faster than angular contours. This finding provides a plausible scenario for the link between perceptual sensitivity and preference associated with curvature.

In *When symmetric and curved visual contour meet intentional instructions: Hedonic value and preference*, we show that while curved and symmetric contours are positive-valenced features, angular and asymmetric contours are negative-valenced features. These findings highlight the multidimensional nature of stimuli, and how the interaction between stimulus features could modulate people's general preferences.

In *Shape familiarity modulates preference for curvature in drawings of common-use objects*, we show that familiarity is a strong predictor of visual preference for curvature. However, our results also reveal that familiarity is not the only factor explaining this preference, because the effect is also present when curved and angular objects are perceived as equally familiar. Together, we conclude that familiarity with

the shape of objects modulates preference for curvature.

In *Humans prefer to see and imagine drawing curved objects*, we find a positive relationship between liking and drawing production preference using curved drawings. Our findings also support the idea of an inconsistent influence of individual differences in preference for curvature.

To summarize, this work yields new empirical evidence of preference for visual curvature and provides a quantitative synthesis of the literature on this effect. We highlight the existence of a reliable and moderate effect of preference for curvature, and some factors that could explain the substantial heterogeneity variance that coexists with the effect. We discuss that the neurophysiological bases of curvature sensitivity may frame the neural bases of preference for curvature. Last, we propose relevant challenges and future directions in light of the upsurge of interest from the humanities, environmental science, and neuroscience in preference for visual curvature.

LAS BASES PSICOLÓGICAS DE LA PREFERENCIA VISUAL POR LA CURVATURA

Resumen

El contorno visual afecta las interacciones entre el ser humano y el medio ambiente. Confiamos en las características del contorno para categorizar, manipular y evaluar objetos. Preferimos objetos con contornos curvos y asociamos la curvatura con sensaciones más positivas que los contornos de ángulos agudos. Esta preferencia se conoce como el efecto de curvatura y ha sido demostrada con diferentes edades, culturas e incluso especies. Sin embargo, la literatura también ha mostrado que el efecto podría ser modulado por varios factores contextuales y de diferencias individuales. Esta disertación sintetiza la literatura científica sobre la preferencia por la curvatura visual y arroja nueva evidencia empírica que aborda los posibles factores moduladores del efecto.

En *How universal is preference for visual curvature? A systematic review and meta-analysis*, mostramos que la preferencia por la curvatura consiste en un efecto fiable y moderado en la literatura. Sin embargo, también mostramos que esta preferencia coexiste con una sustancial variación y heterogeneidad entre estudios. Esta variación es consistente con los efectos moderadores de factores como la tarea, el tipo de estímulo, el tiempo de presentación y la experiencia. En conjunto, estos hallazgos respaldan la idea de que la preferencia por la curvatura está influenciada por factores más allá de la información perceptiva.

En *Circles are detected faster than downward-pointing triangles in a speeded response task*, proponemos que los contornos curvos captan la atención y se procesan más rápido que los contornos angulosos. Este hallazgo proporciona un escenario plausible para el vínculo entre la sensibilidad perceptiva y la preferencia asociada con la curvatura.

En *When symmetric and curved visual contour meet intentional instructions: Hedonic value and preference*, mostramos que mientras los contornos curvos y simétricos son características de valencia positiva, los contornos angulosos y asimétricos son características de valencia negativa. Estos hallazgos destacan la naturaleza multidimensional de los estímulos y que la interacción entre las características del estímulo modula las preferencias generales de las personas.

En *Shape familiarity modulates preference for curvature in drawings of common-use objects*, mostramos que la familiaridad es un fuerte predictor de la preferencia visual por la curvatura. Sin embargo, nuestros

resultados también revelan que la familiaridad no es el único factor que explica esta preferencia, porque el efecto también está presente cuando los objetos curvos y angulosos se perciben como igualmente familiares. En conjunto, concluimos que la familiaridad con la forma de los objetos modula la preferencia por la curvatura.

En *Humans prefer to see and imagine drawing curved objects*, encontramos una relación positiva entre el gusto y la preferencia de producción de dibujos curvos. Nuestros hallazgos también respaldan la idea de una influencia inconsistente de las diferencias individuales en la preferencia por la curvatura.

En resumen, este trabajo aporta nueva evidencia empírica de la preferencia por la curvatura visual y proporciona una síntesis cuantitativa de la literatura sobre este efecto. Destacamos que el efecto de curvatura es confiable y moderado, y discutimos algunos factores que explican la varianza y heterogeneidad que coexiste con el efecto. También, discutimos que las bases neurofisiológicas de la sensibilidad a la curvatura pueden enmarcar las bases neurales de la preferencia por la curvatura. Por último, proponemos desafíos relevantes y direcciones futuras a la luz del aumento del interés de las humanidades, las ciencias ambientales y la neurociencia en la preferencia por la curvatura visual.

LES BASES PSICOLÒGIQUES DE LA PREFERÈNCIA VISUAL PER LA CURVATURA

Resum

El contorn visual afecta les interaccions entre l'ésser humà i el medi ambient. Confiem en les característiques del contorn per categoritzar, manipular i avaluar objectes. Preferim objectes amb contorns corbats i associem la curvatura amb sensacions més positives que els contorns angulars. Aquesta preferència es coneix com l'efecte de curvatura i ha estat demostrada en diferents edats, cultures i, fins i tot, espècies. Tot i això, la literatura també mostra que l'efecte es modulat per diversos factors contextuals i de diferències individuals. Aquesta dissertació sintetitza la literatura científica sobre la preferència per la curvatura visual i presenta nova evidència empírica que aborda els possibles factors moduladors de l'efecte.

A *How universal is preference for visual curvature? A systematic review and meta-analysis*, mostrem que la preferència per la curvatura consisteix en un efecte fiable i moderat a la literatura. Tot i això, també mostrem que aquesta preferència coexisteix amb una substancial variabilitat i heterogeneïtat entre estudis. Aquesta variabilitat és consistent amb els efectes moderadors de factors com ara la tasca, el tipus d'estímul, el temps de presentació i l'experiència dels participants. En conjunt, aquestes troballes donen suport a la idea que la preferència per la curvatura està influenciada per factors més enllà de la informació perceptiva.

A *Circles are detected faster than downward-pointing triangles in a speeded response task*, proposem que els contorns corbats capten l' atenció i es processen més ràpid que els contorns angulosos. Aquesta troballa proporciona un escenari plausible per a l'enllaç entre la sensibilitat perceptiva i la preferència associada a la curvatura.

A *When symmetric and curved visual contour meet instructions instructions: Hedonic value and preference*, mostrem que mentre els contorns corbats i simètrics són característiques de valència positiva, els contorns angulosos i asimètrics són característiques de valència negativa. Aquestes troballes destaquen la naturalesa multidimensional dels estímuls i que la interacció entre les característiques de l'estímul modula les preferències generals de les persones.

A *Shape familiarity modulates preference for curvature in drawings de common-use objects*, mostrem que la familiaritat és un fort predictor de la preferència visual per la curvatura. Tot i això, els nostres

resultats també revelen que la familiaritat no és l'únic factor que explica aquesta preferència, atès que l'efecte també és present quan els objectes corbats i angulosos es perceben com igualment familiars. En conjunt, concloem que la familiaritat amb la forma dels objectes modula la preferència per la curvatura.

A *Humans prefer to see and imagine drawing curved objects*, trobem una relació positiva entre el gust i la preferència de producció de dibuixos corbats. Les nostres troballes també donen suport a la idea d'una influència inconsistent de les diferències individuals en la preferència per la curvatura.

En resum, aquest treball aporta nova evidència empírica de la preferència per la curvatura visual i proporciona una síntesi quantitativa de la literatura sobre aquest efecte. Destaquem que l'efecte de curvatura és fiable i moderat, i discutim alguns factors que expliquen la variabilitat i heterogeneïtat que coexisteix amb l'efecte. També discutim que les bases neurofisiològiques de la sensibilitat a la curvatura poden emmarcar les bases neurals de la preferència per la curvatura. Per últim, proposem reptes rellevants i adreces futures a la llum de l'augment de l'interès de les humanitats, les ciències ambientals i la neurociència en la preferència per la curvatura visual.

THE PSYCHOLOGICAL BASES OF VISUAL PREFERENCE FOR CURVATURE

1. THE STATE OF THE ART

1.1. Preference for curvature: an overview

People find pleasure in some visual features of nature. Examples of these features include symmetry (Bertamini, Rampone et al., 2019), complexity (Eisenman, 1967), balance (Wilson & Chatterjee, 2005), and contour (Gómez-Puerto et al., 2016), among others. Because preference for such features may be shared between individuals, cultures, and even species, they may rely on similar cognitive, affective, and perceptual brain mechanisms. This idea points out the existence of objective visual preferences on the scale of the rigid and universal human evolution. We share an evolutionary history that makes it likely that these features are processed similarly regardless of one's social environment because they are important for survival (Nusslein-Volhard, 2019). Thus, our likes and dislikes might be based on a universal standard of liking characterized by specific features guiding preference, and explaining the apparent sensitivity unique to humankind.

However, we might find equally as many examples of subjective preferences for each of the supposed examples of universal preferences (Nusslein-Volhard, 2019). Although visual preferences depend on similar brain mechanisms among individuals from different cultures, culture shapes the brain both on a sociocultural and individual level (Sapolsky, 2017). Each culture has its own beliefs and values that we learn and embrace. There are no two individuals of the same culture who are exactly alike in their likes and dislikes. Therefore, the roots of preference are probably due to differences in our environment and our experience. What we like or dislike may also be based on flexible and individualized brain mechanisms (e.g., reinforcement learning) that create a substantial variation in preference within and between individuals.

Research on the interplay between objective and subjective factors shaping preference can be dated since early work in the field of Empirical Aesthetics (Chamberlain, 2022). Eysenck searched for a general objective factor of aesthetic appreciation. He measured people's aesthetic taste by subtracting their judgement from a group average conceived as a true aesthetic value (Eysenck, 1941, 1942). Those whose judgements approached the average of the group were highly aesthetically sensitive or had good taste. In contrast, those whose judgement deviated from the average of the group were aesthetically insensitive or had bad taste (Che et al., 2018). Therefore, Eysenck's assumption of aesthetic preference rested on a universal notion that was a common reference to all humans, and largely determined by biological and innate factors (Eysenck, 1941, 1942, 1981). In contrast, Child (1962) was skeptical about Eysenck's assumptions. He conceived aesthetic sensitivity as the ability to appreciate and respond to beauty and art in a meaningful way, cultivated in practice and the result of cognitive style and personality. Therefore, this author suggested that cross-cultural agreement was not the result of a specific innate ability to judge beauty. Instead, he proposed that cross-cultural similarities in judgement are due to cross-cultural similarities in the way extensive experience with art, independent thinking, openness to new experiences, and attraction to challenges influence the appraisal of art (Che et al., 2018). Subsequently, Daniel Berlyne set the trend in the field in the following and last decades. Berlyne (1971, 1974) believed that stimulus preference depended on the amount of potential information transmitted to the organism through psychophysical, ecological, and collative features. His studies provided evidence that aesthetic preference across individuals and cultures is influenced by collative variables such as complexity, symmetry, proportion, and curvature, among others.

Researchers investigate the apparent universality and individual variation in preference for visual features throughout the world. However, how these features shape preference is still far from clear. Here, we focus on the effect of visual curvature. This effect proposes that people prefer curved contours, and that curvature involves more positive feelings than sharp-angled contours (Corradi & Munar, 2020). Preference for curvature has been consistently demonstrated under different experimental conditions (Gómez-Puerto et al., 2016), age (Amir et al., 2011; Fantz, 1961), cultures (Gómez-Puerto et al., 2017), and even species (Ebel et al., 2020; Munar et al., 2015). This scenario has raised the possibility that such preference might be universal. However, a consistent caveat in this literature has pointed out the existence of substantial and reliable differences which do not merely represent variance due to error but can instead be attributed to contextual and person-level variables (Chamberlain, 2022; Corradi, Belman et al., 2019; Corradi, Chuquichambi et al., 2020).

Research on curvature preference has extended in the literature. From the publication of seminal historical (e.g., Hogarth, 1753) and empirical works (e.g., Martin, 1906; Stratton, 1902, 1906), until the development of recent doctoral dissertations such as Madani (2007), Gómez-Puerto (2017), Corradi (2019), Ho (2020), and the present work. Relatedly, research on multisensory experiences has supported a crossmodal correspondence between curvature and sweetness perception, which is partly based on an affective correspondence between shapes and tastes (for two doctoral dissertations, see Velasco, 2015; Salgado-Montejo, 2018). Early studies in preference for curvature mostly evaluated the association of curved stimuli with word sets characterized by specific affective content. Examples of these words are sad, quiet, lazy, merry, agitating, angry, weak, hard, or powerful, among other similar words (Hevner, 1935; Kastl & Child, 1968; Lundholm, 1920; Poffenberger & Barrows, 1924). Other studies evaluated preference for curved stimuli using semantic differential scales (Osgood et al., 1957). These scales can be grouped into three dimensions: Evaluation (e.g., good-bad, friendly-unfriendly, etc.), Potency (e.g., strong-weak, heavy-light, etc.), and Activity (e.g., excitable-calm, active-passive, etc.) (Aronoff, 2006; Aronoff et al., 1992; Uher, 1991). The study of Bar and Neta (2006) crucially influenced how the field developed. These authors briefly presented curved and sharp-angled real object images and meaningless patterns in a like-dislike two-alternative forced choice task. They found that participants preferred curved stimuli more than sharp-angled stimuli. Consequently, they suggested that angular contours were perceived as dangerous and threatening stimuli. Although this proposal provided a new impetus for the field, subsequent studies provided evidence against this hypothesis (Bertamini et al., 2016; Vartanian et al., 2013) and supported curvature as a genuine aesthetic feature (Corradi & Munar, 2020). The current literature describes an uncertain origin of preference for curvature with evidence supporting both an evolutionary and a learning foundation (Gómez-Puerto et al., 2016).

To summarize, preference for visual curvature has become a recurrent and widespread topic in the literature. As noted by Corradi and Munar (2020), many researchers from multidisciplinary fields investigate the effect with an increasing number of studies from the field of Empirical Aesthetics, but also applied domains such as advertising, marketing, packaging, interior design, architecture, urban planning, and security perception. These studies evaluated the effect through a diverse pool of terms such as attractiveness (Leder & Carbon, 2005; Zhang et al., 2006), liking (Bar & Neta, 2006, 2007), pleasantness (Cotter et al., 2017; Silvia & Barona, 2009), preference (Palumbo & Bertamini, 2016; Westerman et al., 2012), beauty (Carbon et al., 2018; Hůla & Flegr, 2016; Vartanian et al., 2019), comfortableness (Jiang et al., 2015; Soranzo et al., 2018), willingness to purchase (Hareli et al., 2016; Simmonds et al., 2019), approach (Dazkir & Read, 2012; Palumbo et al., 2015), wanting (Ruta et al., 2021; Museums et al., 2022), aesthetic sensitivity (Clemente et al., 2021; Corradi, Belman et al., 2019; Corradi, Chuquichambi et al., 2020), and price expectation (Ding et al., 2019; Hareli et al., 2016), among others *(Figure 1)*. Considering the accumulation of evidence, the present work intends to synthesize the literature on preference for visual curvature and construct a more complete framework to understand the psychological bases underlying this preference.

```r
# Get Figure 1.
suppressWarnings(suppressPackageStartupMessages(library(ggplot2)))
suppressWarnings(suppressPackageStartupMessages(library(dplyr)))
suppressWarnings(suppressPackageStartupMessages(library(hrbrthemes)))
suppressWarnings(suppressPackageStartupMessages(library(plotly)))
# Table_Plot can be found here: (https://bit.ly/3Eovaug).
data <- read.csv("Table_PLOT.csv", sep = ";")
data1 <- data %>% filter(Year >= 2000) %>% group_by(Task, Year) %>%
  dplyr::summarise(Studies = n(), .groups = 'drop')
p1 <- data1 %>% ggplot( aes(x=Year, y=Studies, colour = Task)) +
  geom_point(position=position_jitter(h=0.1, w=0.1), alpha = 0.5, size = 4) +
  ggtitle("Evolution of the studies on the curvature effect (21st century)") +
  theme_ipsum() + ylab("Number of tasks")
plot1 <- p1 + scale_y_continuous(limits=c(1, 40))
plot1 <- (gg_plot <- ggplotly(plot1, originalData = TRUE))
```

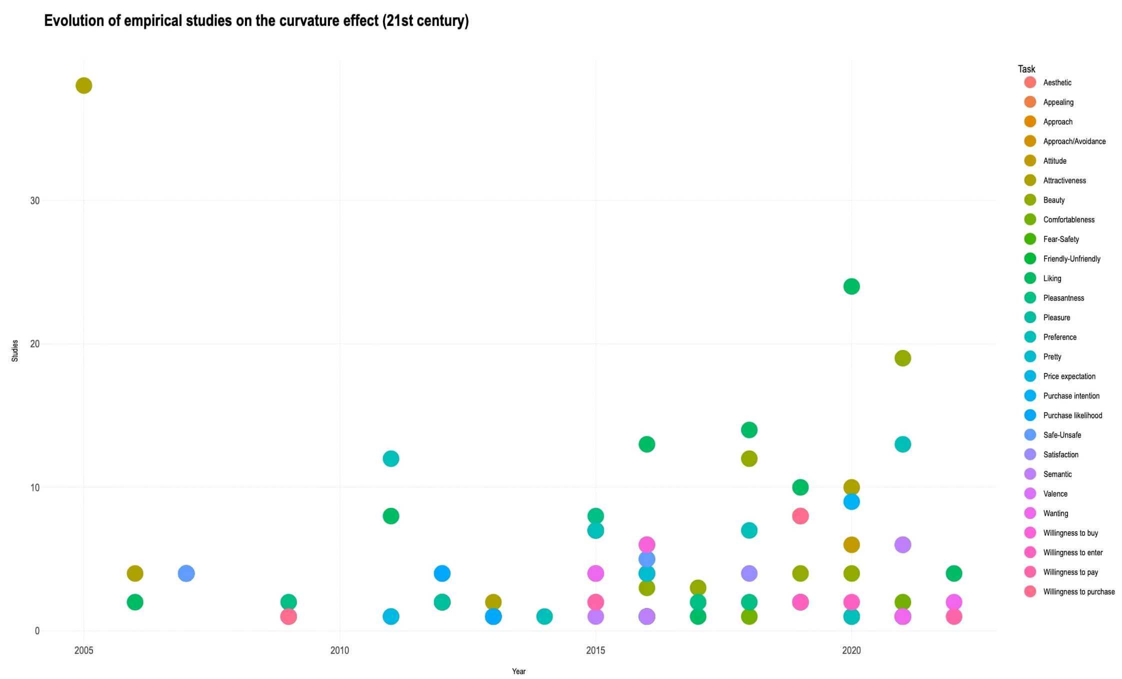

Figure 1: Tasks employed by researchers to evaluate preference for curvature in the 21st century.

1.2. What might modulate visual preference for curvature?

People's visual preferences are affected by intrinsic and extrinsic variables that determine their likes and dislikes. As an example, we do not perceive stimulus features such as curvature as isolated because objects are multidimensional in nature. Object features likely interact, and we tend to prefer some features over others. Early studies in the field of Empirical Aesthetics investigated how visual features interact to define a formal measure of beauty. Birkhoff (1932) proposed beauty as a direct function of the number of order elements (symmetry, equal sides, equal angles, etc.) and an inverse function of the number of complexity elements (number of sides, re-entrant angles, etc.) —M = O / C. In contrast, Eysenck (1968) proposed beauty as a direct function of the number of order elements and a direct function of the number of complexity elements —M = O x C. Subsequent studies also explored the interplay between stimulus features (e.g., Carbon et al., 2018; Makin, 2017). We may expect that a stimulus-preference relation is likely to be modulated when we add another feature or dimension to the stimulus configuration (Makin, 2017). Therefore, how curvature interacts with other object features might change our expected preference tendencies.

People's preference for curved contours may also vary depending on the category of the stimulus. Among other factors, this variance may depend on how meaningful and familiar they perceive the content of the stimulus. On the one hand, meaningful stimuli can include common-use objects (Bar & Neta, 2006), architectural interior designs (Vartanian et al., 2013), and representational drawings (Bertamini & Sinico, 2021), among others. By contrast, meaningless stimuli can include irregular polygons (Bertamini et al., 2016), abstract shapes (Corradi, Rosselló-Mir et al., 2019), and non-representational drawings (Corradi, Belman et al., 2019), among others. We could judge meaningful stimuli as more hedonic, utilitarian, prototypical, or familiar than meaningless stimuli because of the semantic associations with their content. Indeed, along with the collative variables proposed by Berlyne, stimulus prototypicality may also guide aesthetic preference (Martindale et al., 1988). Bar and Neta (2006) reported that the effect of preference for curved real objects was more significant than for curved meaningless patterns. However, Leder et al. (2011) reported that the effect of preference for curved meaningless patterns was more significant than for the same curved objects employed by Bar and Neta (2006). Corradi and colleagues (2019) also employed the same objects as Bar and Neta (2006) and meaningless patterns using short and long display times. These authors reported that the preference for curved real objects decreased as the presentation time increased. However, the preference for curved meaningless patterns increased with longer display times. The authors proposed a higher influence of the meaning and content-related information of representational stimuli as the presentation time increased. Moreover, they suggested that when shapes have no meaning, preference for curvature is preserved or even heightened in long presentation times. They hypothesized that the increased preference for curved meaningless patterns in long display times could reflect better visual discrimination between curved and angular stimuli. That is, as their stimuli only varied in contour type, participants could have based their choices on this difference to a greater extent. As such, the effect of curvature could explain the increase in the number of curved stimuli chosen. Complimentary, these authors speculated that participants could have attributed meaning to the patterns in longer display times. Therefore, since curved features are more prevalent in natural scenes (Bertamini et al., 2019), the curved versions could easily have been matched to natural and real stimuli, leading to increasing preference. Together, the findings of these studies support the notion that contextual variables affect preference for curvature in flexible ways.

In our experiments, we usually ask participants to rate a stimulus (e.g., attractiveness, pleasantness, liking, etc.) or to choose between two-alternative responses (e.g., approach or avoid, like or dislike, etc.). These tasks can be described as continuous outcome measures because they provide independent mean values for each of the compared groups (e.g., liking responses for the curved and sharp-angled stimuli). In contrast, sometimes we ask participants to choose between two-alternative stimuli (e.g., curved or sharp-angled, round or angular) presented at the same time (e.g., Corradi, Rosselló-Mir et al., 2019; Gómez-Puerto et al., 2017). These tasks can be described as dependent dichotomous outcome measures because they provide complementary preference values for each of the compared groups. For example, when participants select the curved stimuli 80% of the time, this also means that they select the sharp-angled stimuli 20% of the time, the two preference values being dependent on each other. Given this scenario, we may expect that participants' preference also varies depending on whether they have to give their response by attending to one or two stimuli at the same time.

Noteworthy, participants' individual factors (i.e., personality traits, cognitive styles, etc.) and socio-cultural background may also determine the magnitude of preference for visual curvature. Some studies indicated that variables such as expertise (Silvia & Barona, 2009) or openness to experience (Cotter et al., 2017) affect preference for curvature. Vartanian and colleagues (2019) found the effect of curvature in both beauty and approach-avoidance judgements of interior architectural spaces. However, experts were less susceptible to curvilinear interior spaces when they were asked for approach-avoidance actions, indicating that the aesthetic judgement of curvature can be disentangled from the positive emotions and pleasure associated with curvature. Interestingly, Palumbo et al. (2020) found that quasi-experts in industrial design liked the rectilinear architectural spaces more than curvilinear ones. This finding supports the idea that the effect of expertise on preference for curvature could change depending on the level of expertise of the participants, as well as the specific knowledge acquired in their discipline. In contrast, other studies did not find any relationship between expertise and preference for curvature (e.g., Corradi, Belman et al., 2019). Regarding the sociocultural background, some studies also provided evidence of the malleability of the effect. Although Gómez-Puerto et al. (2016) indicated that preference for curvature was common across cultures, Zhang et al. (2006) reported that countries high in individualism (e.g., United States, United Kingdom, Canada, and Germany) tend to use more angular logos than countries high in collectivism (e.g., Japan, Hong Kong, and South Korea). In this line, Maezawa et al. (2020) reported that the effect of curvature was situation-dependent in Japanese observers as compared to western observers. Altogether, these studies indicate that individuals' variability and sociocultural factors may contribute to explaining some of the mixed findings reported in preference for curvature literature.

To summarize, in the present work, we also evaluate which variables challenge the robustness of the effect of curvature and, therefore, predict different patterns of contour preference. Previous studies have indicated that contextual, personal, and task-related variables affect preference for curvature (for a review, see Corradi & Munar, 2020). Notably, the influence of these variables also should be evaluated in conjunction. For example, comparing meaningful and meaningless stimuli in continuous outcome measures (Bar & Neta, 2006, 2007; Maezawa et al., 2020) and dichotomous outcome measures (Corradi, Rosselló-Mir et al., 2019); or recruiting participants with expertise in the arts (Corradi, Belman et al., 2019; Silvia & Barona, 2009), in the design of architectural spaces (Dazkir & Read, 2012; Vartanian et al., 2013, 2019), or with different academic backgrounds (Palumbo et al., 2020). Addressing these points may allow us to test how robust the effect of curvature is and explain the cognitive mechanisms underlying this preference.

2. OBJECTIVES

In this dissertation, we synthesize empirical evidence on preference for visual curvature. Specifically, we have addressed the following research objectives:

1. To synthesize the literature on preference for visual curvature to quantify its magnitude and examine its sources of variability.

   The validity of any apparent universal effect requires its ongoing evaluation (Flake et al., 2017). With this idea in mind, we conducted the first systematic review and meta-analysis of preference for visual curvature (Chuquichambi, Vartanian et al., 2022). This meta-analysis provides a more comprehensive framework of the effect of curvature which shows increasing interest in both theoretical and applied research domains.

   In the meta-analysis, we estimated the true effect underlying preference for curvature. The study was designed following a pre-defined protocol and meta-analytical strategy. This quantitative approach contributes to a better understanding of how reliable the effect of curvature is and, therefore, constructs a solid framework for advancing the field.

2. To investigate the contextual and person-level factors that could make a person prefer curvature or angularity.

   Although preference for curvature is a well-known effect in the scientific literature, many studies suggest that it coexists with remarkable variation and heterogeneity at an individual level. In other words, the effect may be conditioned when other variables are present in the experimental design. Heterogeneity can be defined as the presence of variation in true effect sizes underlying the different studies (Higgins, 2008). In this case, heterogeneity may arise because of differences among research disciplines, task-related variables, or participants' characteristics. However, heterogeneity may also arise because of variability among studies within the same field, and even within a single study including multiple measures or samples of participants. Therefore, heterogeneity should be expected when we quantitatively assess preferences such as the effect of curvature. In this vein, addressing the sources of variance may help us challenge the robustness of curvature preference and predict under which conditions we could expect distinct patterns of contour preferences.

3. To advance the understanding of the cognitive mechanisms underlying curvature preference.

   Preference for curvature involves both a sensory-motor and affective component. This objective intended to gain insight into the mechanisms that link these components. Specifically, we examined the perceptual sensitivity to detect curved shapes in speeded response tasks and the affective values associated with curved stimuli. We also discussed this objective in light of the upsurge of interest in understanding the neural bases of curvature preference, and its application to domains such as architecture, design, urban planning, and security perception, among others.

The listed objectives are supported by the first systematic review and meta-analysis of the literature (Chuquichambi, Vartanian et al., 2022), and four empirical articles published in peer-reviewed journals:

- In *Circles are detected faster than downward-pointing triangles in a speeded response task* (Chuquichambi et al., 2020), we found that curved shapes captured attention faster than angular shapes. This finding could support the possible link between perceptual sensitivity and preference associated with curvature.
- In *When symmetric and curved visual contours meet intentional instructions: Hedonic value and preference* (Chuquichambi, Corradi et al., 2021), we investigated the interaction between contour and symmetry visual features using implicit and explicit measures.
- In *Shape familiarity modulates preference for curvature in drawings of common-use objects* (Chuquichambi, Palumbo et al., 2021), we examined whether familiarity with the shape of objects influenced preference for curvature. We also explored whether the artistic expertise, openness to experience, unconventionality, and type of intuition of participants affected contour preference.
- In *Humans prefer to see and imagine drawing curved objects* (Chuquichambi, Sarria et al., 2022), we investigated the relationship between preference for curvature and drawing production preference. We also explored the influence of art experience and openness to experience in this relationship.

Publication list

Chuquichambi, E.G., Vartanian, O., Skov, M., Corradi, G.B., Nadal, M., Silvia, P.J. & Munar, E. (2022). How universal is preference for visual curvature? A systematic review and meta-analysis. *Annals of the New York Academy of Sciences, 1518*(1), 151-165. https://doi.org/10.1111/nyas.14919

Chuquichambi, E.G., Rey, C., Llames, R., Escudero, J.T., Dorado, A. & Munar, E. (2020). Circles are detected faster than downward-pointing triangles in a speeded response task. *Perception, 49*(10), 1026–1042. https://doi.org/10.1177/0301006620957472

Chuquichambi, E.G., Corradi, G.B., Munar, E. & Rosselló-Mir, J. (2021). When symmetric and curved visual contours meet intentional instructions: Hedonic value and preference. *Quarterly Journal of Experimental Psychology, 74*(9), 1525-1541. https://doi.org/10.1177/17470218211021593

Chuquichambi, E.G., Palumbo, L., Rey, C. & Munar, E. (2021). Shape familiarity modulates preference for curvature in drawings of common-use objects. *PeerJ, 9*, e11772. https://doi.org/10.7717/peerj.11772

Chuquichambi, E.G., Sarria, D., Corradi, G.B. & Munar, E. (2022). Humans prefer to see and imagine drawing curved objects. *Empirical Studies of the Arts, 41*(1), 135-156. https://doi.org/10.1177/02762374221084212

3. PUBLICATIONS

```r
# Get a table with the contributions made by the PhD candidate in each publication.
suppressWarnings(suppressPackageStartupMessages(library(knitr)))
suppressWarnings(suppressPackageStartupMessages(library(kableExtra)))
table1 <- data.frame(Cat=c("Conceptualization","Methodology","Software","Data curation",
"Data analysis","Visualization","Writing","Review/Editing"),`Publication 1`=c("","*",
"*","*","*","*","*","*"),`Publication 2`=c("","*","*","*","*","*","*","*"),
`Publication 3`=c("","*","*","*","*","*","*","*"),`Publication 4`=c("*","*","*","*",
"*","*","*","*"),`Publication 5`=c("*","*","*","*","*","*","*","*"))
kable(table1,col.names=c("","1","2","3","4","5"),align=rep('c',4),escape=F,caption=
"Tasks done by the PhD Candidate in each publication.")%>%kable_styling(latex_options=
"HOLD_position",full_width=TRUE) %>%
  add_footnote(c("Chuquichambi, Vartanian et al. (2022)", "Chuquichambi et al. (2020)",
  "Chuquichambi, Corradi et al. (2021)","Chuquichambi, Palumbo et al. (2021)",
  "Chuquichambi, Sarria et al. (2022)"), notation = "number")
```

Table 1: Tasks done by the PhD Candidate in each publication.

	1	2	3	4	5
Conceptualization				*	*
Methodology	*	*	*	*	*
Software	*	*	*	*	*
Data curation	*	*	*	*	*
Data analysis	*	*	*	*	*
Visualization	*	*	*	*	*
Writing	*	*	*	*	*
Review/Editing	*	*	*	*	*

[1] Chuquichambi, Vartanian et al. (2022)

[2] Chuquichambi et al. (2020)

[3] Chuquichambi, Corradi et al. (2021)

[4] Chuquichambi, Palumbo et al. (2021)

[5] Chuquichambi, Sarria et al. (2022)

3.1. How universal is preference for visual curvature? A systematic review and meta-analysis

Chuquichambi, E.G., Vartanian, O., Skov, M., Corradi, G.B., Nadal, M., Silvia, P.J. & Munar, E. (2022). How universal is preference for visual curvature? A systematic review and meta-analysis. *Annals of the New York Academy of Sciences, 1518*(1), 151-165. https://doi.org/10.1111/nyas.14919

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REVIEW

ANNALS OF THE NEW YORK ACADEMY OF SCIENCES

How universal is preference for visual curvature? A systematic review and meta-analysis

Erick G. Chuquichambi[1] | Oshin Vartanian[2] | Martin Skov[3,4] | Guido B. Corradi[5] | Marcos Nadal[1] | Paul J. Silvia[6] | Enric Munar[1]

[1]Human Evolution and Cognition Group (EvoCog), University of the Balearic Islands, Palma de Mallorca, Spain

[2]Department of Psychology, University of Toronto, Toronto, Ontario, Canada

[3]Danish Research Centre for Magnetic Resonance, Copenhagen University Hospital Hvidovre, Hvidovre, Denmark

[4]Decision Neuroscience Research Cluster, Copenhagen Business School, Frederiksberg, Denmark

[5]Department of Psychology, Faculty of Health, University Camilo José Cela, Madrid, Spain

[6]Department of Psychology, University of North Carolina at Greensboro, Greensboro, North Carolina, USA

Correspondence
Erick G. Chuquichambi, Human Evolution and Cognition Group (EvoCog), University of the Balearic Islands, Palma de Mallorca, Spain.
Email: erik.chuquichambi@uib.es

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Abstract

Evidence dating back a century shows that humans are sensitive to and exhibit a preference for visual curvature. This effect has been observed in different age groups, human cultures, and primate species, suggesting that a preference for curvature could be universal. At the same time, several studies have found that preference for curvature is modulated by contextual and individual factors, casting doubt on this hypothesis. To resolve these conflicting findings, we conducted a systematic meta-analysis of studies that have investigated the preference for visual curvature. Our meta-analysis included 61 studies which provided 106 independent samples and 309 effect sizes. The results of a three-level random effects model revealed a Hedges' g of 0.39—consistent with a medium effect size. Further analyses revealed that preference for curvature is moderated by four factors: presentation time, stimulus type, expertise, and task. Together, our results suggest that preference for visual curvature is a reliable but not universal phenomenon and is influenced by factors other than perceptual information.

KEYWORDS
contour, hedonic liking, preference, vision, visual curvature

INTRODUCTION

Contour is a core aspect of visual perception that plays a fundamental role in the detection and representation of objects.[1] Contour integration binds disjointed parts of a scene into coherent global shapes and helps demarcate the interior of an object from its exterior.[2,3] The structure of object shapes is among the primary sources of information determining how objects are recognized.[4] When asked to identify "what is this object?" people base their answers mainly on the shape and material properties of the perceived contour. In this sense, contour plays a critical role in how people perceive their surroundings and the objects within them.

Contour also informs how pleasing or displeasing objects are experienced to be. Early work dating back over a century sought to examine the effect that contour has on people's feelings.[5–7] Those studies manipulated contour using stimuli, such as lines or abstract displays, and consistently showed that curvilinear forms are experienced as softer and more pleasant than angular forms, which are in turn experienced as harder and more serious. In other words, there was early recognition that contour can have an impact on the viewer's affective system, as reflected by Gordon's[8] assessment that "curves are in general felt to be more beautiful than straight lines. They are more graceful and pliable, and avoid the harshness of some straight lines." This early association between visual form and affect set the stage for examining the effect of contour on hedonic valuation.

More recently, a great number of studies have found that objects that exhibit curvilinear contour are preferred to objects that exhibit angular contour (for reviews, see Refs. 9 and 10). In addition to abstract and isolated forms and lines,[11] this preference for curvilinear contours has been observed across a wide range of objects, including everyday artifacts and natural entities, building facades, interior rooms, as well as visual art.[12–16]

Because curvilinear forms appear to be more liked than angular forms irrespective of object category, it has been suggested that this preference has been selected for in the course of human evolution.[17,18] Bar and Neta[12,19] proposed that humans experience angular contour as unpleasant because this perceptual feature has become associated with threatening and dangerous objects. Curvilinear contour, they proposed, evokes feelings of pleasure, either because curvilinear objects signal an absence of danger, or because they have been associated with rewarding behavior throughout human evolution. In this sense, associating angularity with threat and curvilinear contour with reward can be seen as another example of "snap judgments" that people make about objects in their environment to maximize their chances of survival.

Over the last two decades, numerous behavioral and neuroscientific studies have tested this hypothesis. Unfortunately, evidence for and against it has been both mixed and inconclusive. Thus, some studies support the contention that human preference for curvature is universal, and, therefore, possibly innate.[20] For example, Gómez-Puerto and colleagues[21] found that nonwestern participants in Mexico and Ghana prefer objects with curvilinear contour, as do participants in Spain. There is also mounting evidence that infants and children look longer at curvilinear than angular objects,[22–29] suggesting that evaluative responses to curved and angular objects may be present at birth. Finally, recent experiments have found evidence that chimpanzees and gorillas,[30] as well as orangutans,[31] also prefer objects that have curvilinear rather than angular contour. The observation of preference for curvature across different age groups, human cultures, and primate species is consistent with a possible universality of the effect.

Other experiments, however, have found compelling evidence that preference for curvature is influenced by both subjective sensitivity to contour features, as well as contextual factors. In two important studies, Corradi and colleagues[32,33] demonstrated that a group of participants who collectively exhibit a greater preference for curvilinear than angular stimuli also contains a nontrivial number of participants who do not share this general predilection. This finding suggests that some people's hedonic response to contour information differs from the majority's, implying that the observed preference pattern might not be universal after all. Possible sources of this variance include the kind and degree of exposure and knowing what the individual has been exposed to, among others. For example, people who have acquired an expertise-level understanding of architectural design report a diminished liking for curvature combined with an enhanced liking for angular objects under certain conditions.[34] Such evaluations may be particularly dependent on expertise because it supports the cognitive processing of the stimulus at different stages of the aesthetic experience.[35] In addition, studies have also found that differences in personality[36] and psychiatric conditions, such as autism spectrum disorder, can influence how individuals respond to stimuli with different contours.[37,38] Because persons with autism spectrum disorder exhibit a different constellation of emotional and perceptual processes compared to neurotypical controls, these findings suggest that preference for curvature is influenced by factors that vary across individuals due to the ways in which they might perceive and appraise objects in their environments, in a similar way to what has been observed in the case of symmetry.[39]

Contextual factors can also modulate the hedonic outcome of exposure to curvilinear and angular objects. Corradi and colleagues[40] found participants' propensity for choosing curvilinear over angular objects diminished when choices were not restrained by response time constraints. This suggests that preference for curvature emerges rapidly, and that its effect can be attenuated by top-down processes that could exhibit themselves downstream in the processing pathway (e.g., semantics). Similarly, Palumbo and Bertamini[41] collected two-alternative forced-choice responses (like vs. dislike) made during a fixed display window (i.e., 120 ms), and compared those with self-paced continuous liking ratings, and found that preference for curvilinear objects was slightly more pronounced under the former than the latter condition. This too is consistent with the idea that the effect is stronger under conditions that favor quick, snap judgments. These authors also found that participants prefer curvilinear objects with a smaller number of vertices and a higher number of concavities when using the self-paced rating scale as the evaluative anchor. Together, these results suggest that contextual conditions—including stimulus features, presentation time, and evaluative anchors—can affect the way in which contour information becomes evaluated, resulting in the assignment of different degrees of liking or disliking to objects with curvilinear and angular contour.

Finally, it remains unclear how the human brain computationally implements hedonic evaluations of curvature in the visual domain. The innateness hypothesis posits that representations of curvilinear contour engage neural processes associated with the generation of pleasure, while representations of angular contour engage neural systems involved in producing defensive emotional states such as fear. Using functional magnetic resonance imaging (fMRI), Bar and Neta[19] found that angular objects elicit greater activity in the amygdala than curvilinear objects. They interpreted this result as potential evidence that exposure to angular objects produces a fear response that signals threat and danger. However, they found no evidence that pleasure-related neural structures respond differently to curvilinear compared to angular objects. Vartanian and colleagues'[16] fMRI experiment in the domain of architecture reported a different pattern of results to Bar and Neta's.[19] Specifically, in relation to the neural activity associated with beauty judgments, Vartanian et al.[16] found that rooms with curvilinear designs elicit greater activity in the anterior cingulate cortex (ACC) than rooms with angular designs. The ACC is a key structure within the neural system involved in the computation of core affect.[42,43] Furthermore, given its strong resting-state connectivity with both the orbitofrontal cortex and the anterior insula, it is presumed to underlie emotional salience monitoring.[44] Hence, the observed activation in the ACC could be explained as a difference in the amount of subjective pleasure experienced by the participants in response to the two categories of stimuli. Indeed, data collected outside of the fMRI scanner demonstrated that pleasantness ratings accounted for the majority of variance in beauty judgments. Yet, while this result suggests that curvilinear rooms might become liked by engaging appetitive affective processes, Vartanian and colleagues[16] did not observe any difference in the modulation of amygdala activity by the two stimulus classes, or activation in regions of the brain that underlie the perception of visual features, including contour. Understanding the neurobiological bases of the evaluation of features such as contour may lie in charting the dynamics of the networks that integrate these regions.[45]

To make sense of this contradictory body of work, we conducted a systematic review and meta-analysis of studies reporting hedonic evaluations of stimuli varying in contour in the visual domain. We aimed to assess the average effect size of preference for curvature across different stimulus types, experimental paradigms, contexts, and populations. This analysis had two goals: (1) ascertaining how universal liking for curvature truly is and (2) identifying factors that might moderate its effect size across different conditions.

MATERIALS AND METHODS

Protocol and registration

A preliminary protocol was made publicly accessible on the Open Science Framework (https://osf.io/58n23/) prior to data collection. The method for this systematic review and meta-analysis was developed in line with the PRISMA-P guidelines.[46] The meta-analysis examined studies comparing curvilinear (i.e., curved, smooth, round, and circular) and angular (i.e., rectilinear, straight, sharp-angled, jagged, squared, pointed, and rectangular) visual stimuli in behavioral preference measures. Most of the studies on preference for curvature investigated the effect using continuous outcome measures. These measures provide independent mean values for each one of the groups compared (e.g., curvilinear vs. angular). In addition, a smaller set of studies investigated the effect using dependent dichotomous measures.[21,30,32,40,47–53] These measures provide complementary preference values for each one of the groups compared. That is, in these studies, a curvilinear stimulus and an angular stimulus are presented simultaneously, and participants choose one of the two stimuli. Consequently, when participants select a stimulus 80% of the time, this also means that the other stimulus is selected 20% of the time, which indicates that the preference values are complementary to each other. Given the divergence between continuous and dependent dichotomous measures, the present analysis focused exclusively on continuous measures such as those using rating scales (e.g., liking) and two-alternative responses (e.g., like-dislike). However, although we did not include data from studies that employed dependent dichotomous outcomes or studies focusing on other measures, such as response times and eye movements in our meta-analysis, they are nevertheless discussed throughout the meta-analysis because they provide valuable insight into this effect.

Eligibility criteria

The following criteria were established for eligible studies: (1) The study was empirical or experimental research published in a peer-reviewed journal, it was presented as a doctoral dissertation, or it was presented at an international conference. Studies that focused on theoretical or conceptual aspects were excluded (e.g., Refs. 9 and 10). (2) Participants were human adults. Studies conducted with nonhuman samples (e.g., Refs. 30 and 31), infants or children (e.g., Refs. 25 and 54) were excluded. (3) The study was written in English. Studies written in other languages were excluded (e.g., Refs. 55 and 56). (4) The study was conducted with a neurotypical sample of participants. Studies that targeted clinical populations were excluded (e.g., the autism spectrum condition group from Palumbo et al.[37]). (5) The study compared curvilinear (i.e., curved, smooth, round, and circular) and angular (i.e., rectilinear, straight, sharp-angled, jagged, squared, pointed, and rectangular) visual stimuli. Studies whose results focused on another sensory modality (e.g., Ref. 57) or did not include curvilinear or angular stimulus categories (e.g., Ref. 58) were excluded. (6) The measures of the study were based on personal preference. Measures based on reaction times (e.g., Refs. 59 and 60), and eye movement patterns or neurophysiological results (e.g., Ref. 24) were excluded. (7) The study employed a continuous outcome measure, such as a rating scale, or a two-alternative procedure (e.g., like-dislike and approach-avoidance). Studies using dependent dichotomous outcome measures (e.g., Refs. 21 and 33) were excluded. No temporal constraint was settled for the year of publication of the study.

Search strategies

The search of studies followed the strategies described in the protocol, and it was conducted on February 21, 2021. First, the search of studies was carried out via the electronic databases EBSCOHost—PsycINFO, PubMed, and Web of Science (WoS). We employed generic searches within the Title, Abstract, and Keywords using the following combination of terms: (curvature OR curvilinear OR smooth OR round OR curved), (sharp-angled OR angular OR straight OR rectilinear), (contour OR shape), AND (aesthetics OR preference OR liking OR beauty). Second, the search of studies was carried out via journal searches within six relevant journals in the domain of empirical aesthetics: Psychology of the Aesthetics, Creativity, and The Arts; Empirical Studies of the Arts; Perception; i-Perception; Acta Psychologica; and British Journal of Psychology. Lastly, after screening all the studies against eligibility criteria, manual “backward” and “forward” search from the citation and reference lists of the remaining studies was implemented via the Google Scholar search engine (see the Supplementary Information for additional details on the literature search process).

Study selection

The initial search of studies provided 696 studies via database searching and 77 studies via journal searching. After the literature search, two authors independently screened the studies against inclusion criteria. In cases of discrepancies, a third author screened the studies again to reach an agreement among the authors. When a study did not report the necessary data to calculate all the effect sizes, the authors were contacted via e-mail and asked whether it was possible to obtain the data to calculate an effect size. In cases of no response and when the studies represented relevant values in plots (i.e., means, confidence intervals, or standard errors), we used a web plot digitizer[61] to convert plotted representations into numerical values. Conversely, when these studies had no available plots, they were excluded because of insufficient data for calculating effect sizes.

Data extraction and management

Data were extracted in accordance with the PRISMA-P guidelines.[62] According to the protocol, the following basic information was extracted from the studies meeting eligibility criteria: (1) author/s name/s, (2) year of publication, (3) title of the study, (4) journal/conference name, (5) study design (within-subjects vs. between-subjects), (5) sample size, (6) number of male and female participants, (7) mean age and standard deviation, (8) mean and standard deviation (or standard error) values of curvilinear and angular preference. We identified wide variability among the concepts employed by researchers to measure preference for curvature in the visual domain. Therefore, deviating from the protocol, this variable was also extracted and analyzed along with the other possible moderator variables registered in the protocol: (9) task (i.e., the construct used to measure the curvature effect), (10) stimulus type, (11) presentation time of the stimuli, (12) measure (i.e., whether preference was measured using a rating scale or two-alternative response options), and (13) expertise (e.g., architects, designers, art students, and laypeople). Additional variables considered for exploratory analyses were extracted and coded as follows: (14) data collection procedure (in-person vs. online, paper-based, computer-based, web-based, projection screen-based, and tablet-based), and (15) verbal terminology (e.g., curvilinear/rectilinear, round/angular, curved/sharp, curved/angular, round/sharp, circular/rectangular, etc.). Lastly, we also coded (16) the stimulus dimensionality (two-dimensional vs. three-dimensional) and (17) digitization (i.e., whether the study plots were digitized or not [only in cases of insufficient data to calculate effect sizes and if plots were available] to perform sensitivity analyses).

The variable *task* indicates the evaluative construct researchers asked participants to assess when responding to curvilinear and angular stimuli. It included terms, such as approach/avoidance, attractiveness, beauty, comfortableness, valence, liking, pleasantness, preference, price expectation, intention to purchase, and wanting, among others. Given the wide terminology employed by researchers, we categorized the terms into five distinct categories: artistic, semantic, economic, hedonic, and magnetic. The *artistic* task (k = 42) included the experiments using the concepts beauty, beautiful/ugly, and beauty/not beauty, which were typically used in studies of art objects. The *semantic* task (k = 35) included the experiments using the bipolar adjectives good/bad, positive/negative, dangerous/safe, safe/unsafe, fear/safety, aggressive/peaceful, hostile/friendly, threatening/protective, harsh/gentle, irritated/balanced, sad/cheerful, and comforting/not comforting. This categorization was based on the semantic differential scales of the evaluative dimension proposed by Osgood et al.[63] to measure the value of an object. The *economic* dimension (k = 31) included the experiments where participants were instructed to indicate purchase likelihood, willingness to buy, willingness or intention to purchase, price expectation, and price to pay. The *hedonic* task (k = 184) included the experiments using the terms attractiveness, liking, pleasantness, preference, and appealing. Lastly, the *magnetic* task (k = 17) included experiments using attraction-related terms, including approach, approach/avoidance, willingness to enter/exit, and wanting.

The variable *stimulus type* was coded using four levels: object (k = 123), meaningless (k = 83), spatial design (k = 73), and symbolic design (k = 30). Within the domain of empirical aesthetics, several studies have documented a preference for curvature using real objects as well as meaningless stimuli (e.g., Refs. 12, 19 and 64). Corradi and Munar also noted an increasing number of studies examining preference for curvature from applied research fields (i.e., advertising, marketing, packaging, and interior design). These authors described the stimuli from these studies as item forms, product packaging or logos, and general settings. Therefore, influenced by the review of Corradi and Munar,[10] we also included as stimulus type the levels "spatial design" (e.g., interior designs, architectural façades, etc.) and "symbolic design" (e.g., logos, typefaces, etc.).

Regarding the variable *presentation time* (of the stimulus), it varied across studies from relatively brief presentation times (e.g., 84, 85, 90, 120, 500, 1500, 2000, 3000, and 7000 ms) to studies that allowed unlimited time for responding. However, we found that the number of effect sizes within each specific presentation time was small. Therefore, we coded this variable into two levels: limited (k = 50; i.e., from 84 to 7000 ms) and unlimited (k = 259, i.e., until response) presentation times for the stimuli. The variable measure indicates whether the task used by researchers was a continuous measure (k = 275; e.g., rating scale) or a continuous dichotomous measure (k = 34; e.g., like-dislike two-alternative forced choice procedure).

Finally, the variable *expertise* indicates whether a study included participants qualified as experts or quasi-experts. Some examples include working architects and designers who were presented with images of architectural interior designs,[34] orthodontists and restorative dentists presented with pictures of teeth,[65] and university-level design students presented with images of architectural interiors.[37] We coded this variable in three levels: experts ($k = 34$), quasi-experts ($k = 8$), and nonexperts ($k = 267$).

Meta-analytic strategy

Data analysis was carried out with the R environment for statistical computing,[66] using the "metafor" package.[67] We noted that several studies provided multiple effect sizes using the same sample of participants. A critical assumption in random- and mixed-effects meta-analyses is that the effect sizes are independent. When the effect sizes in a meta-analysis are not independent, the estimated standard errors for the average effect are underestimated.[68] Therefore, deviating from the protocol, we handled the dependencies between the effect sizes with a three-level random effects meta-analysis with restricted maximum likelihood.[69,70] The three-level meta-analysis model is an extension of the random-effects meta-analysis model.[71] This model divides variability in effect sizes into the sampling variation for each effect size (Level 1), variation across multiple effect sizes within a study (Level 2), and variation across studies (Level 3).[72,73] Thus, compared to other approaches, a three-level meta-analysis allows researchers to study and decompose heterogeneity variances at different levels.

We conducted a study of influential cases based on Cook's distance (Di), which indicates the relative influence of each effect size on the summary estimate. As a standard rule of thumb, Di values greater than three times the mean Di were considered influential cases[74] (17 effect sizes from 14 studies[32,41,48,53,64,75–83]). In addition, two more sensitivity analyses were performed separated by repeating the models without the effect sizes extracted from the values represented in plots (19 effect sizes from eight studies[53,76,84–89]), and without the effect sizes of studies using real (three-dimensional) stimuli (26 effect sizes from 10 studies[75,76,79,82,84,85,87,90–92]).

We fitted moderator models to evaluate how specific variables accounted for the variability among effect sizes. We considered as potential moderators of preference for curvature the variables *task* (i.e., artistic, economic, semantic, hedonic, and magnetic), *stimulus type* (meaningless, object, spatial design, and symbolic design), *presentation time* (limited vs. unlimited), *measure* (continuous vs. continuous dichotomous), and *expertise* (experts, quasi-experts, and nonexperts). Lastly, exploratory analyses were also considered with the variables, including *year of publication*, *task modality* (in-person vs. online, paper-based, computer-based, web-based, projection screen-based, and tablet-based), and *verbal terminology* (e.g., curved/sharp, curvilinear/rectilinear, round/angular, etc.).

RESULTS

We consider Hedges' g for a 95% confidence interval as the main summary measure. Hedges' g provides an unbiased estimate of the effect size because it does not overestimate the magnitude of the effect of studies with small sample sizes.[93] We interpret values of 0.15, 0.40, and 0.70 as small, medium, and large effects, respectively.[94] Unless otherwise indicated, all analyses were preregistered (https://osf.io/58n23/).

Included effect sizes

The initial search of studies provided 696 studies via database searching, and 77 studies via journal searching. The removal of duplicate studies left 612 studies to be screened for eligibility. Of those, 548 studies were excluded because their title and abstract did not fit the subject matter of the meta-analysis. Full-text screening of the 64 remaining studies resulted in the inclusion of 30 in the meta-analysis. Manual "backward" and "forward" search from citation and reference lists of the remaining studies provided 27 additional studies from reference lists and 24 additional studies from citation lists. In total, 81 studies were identified for inclusion, providing a pool of 141 independent samples and 418 effect sizes. The process of gathering data from these studies revealed that 42 studies missed the data that were relevant to the calculation of effect sizes. The authors of 16 of these studies provided raw data when contacted, but two of these datasets were impossible to interpret. The authors of three other studies reported that the data were no longer accessible, the authors of 15 studies did not reply, and the authors of two studies could not be contacted because of a lack of viable contact information. Therefore, of the 42 studies with missing data, we were unable to retrieve data relevant to the calculation of effect sizes from 28 studies. Eight additional studies were included by obtaining the summary scores represented in reported plots.[53,76,84–89] Studies without available plots were excluded because of insufficient data. All in all, of the 81 studies meeting inclusion criteria, 61 studies were included in the final meta-analysis. Figure 1 depicts a flowchart with detailed information on the literature search and the inclusion process.

The 61 studies included in the analysis yielded 106 independent samples and 309 effect sizes (Figure 2). Statistics for the effect sizes and the samples of the studies are summarized in Table 1 (11,023 participants, $M_{age} = 27.81$, $SD_{age} = 7.34$).

Confirmatory hypothesis testing

First, we ran the three-level random effects model and two additional two-level random effects models without Levels 2 (within-study variance) and 3 (between-study variance), respectively. Model fit indices significantly improved when three levels were included in the analysis suggesting that within-study and between-study variance were both statistically significant. Results revealed a moderate effect of preference for curvature ($g = 0.39$, $t = 5.66$, $p < 0.001$, 95% CI [0.25, 0.52]). Level 3 accounted for more heterogeneity (77.67%) than Level 2 (14.38%), demonstrating that in a two-level model, heterogeneity is incorrectly attributed only to the second level (Table 2). In addition, we ran a random-effects model without handling the dependencies between effect sizes, which produced a slightly smaller effect than the three-level model ($g = 0.32$, $z = 10.89$, $p < 0.001$, 95% CI [0.26, 0.38]).

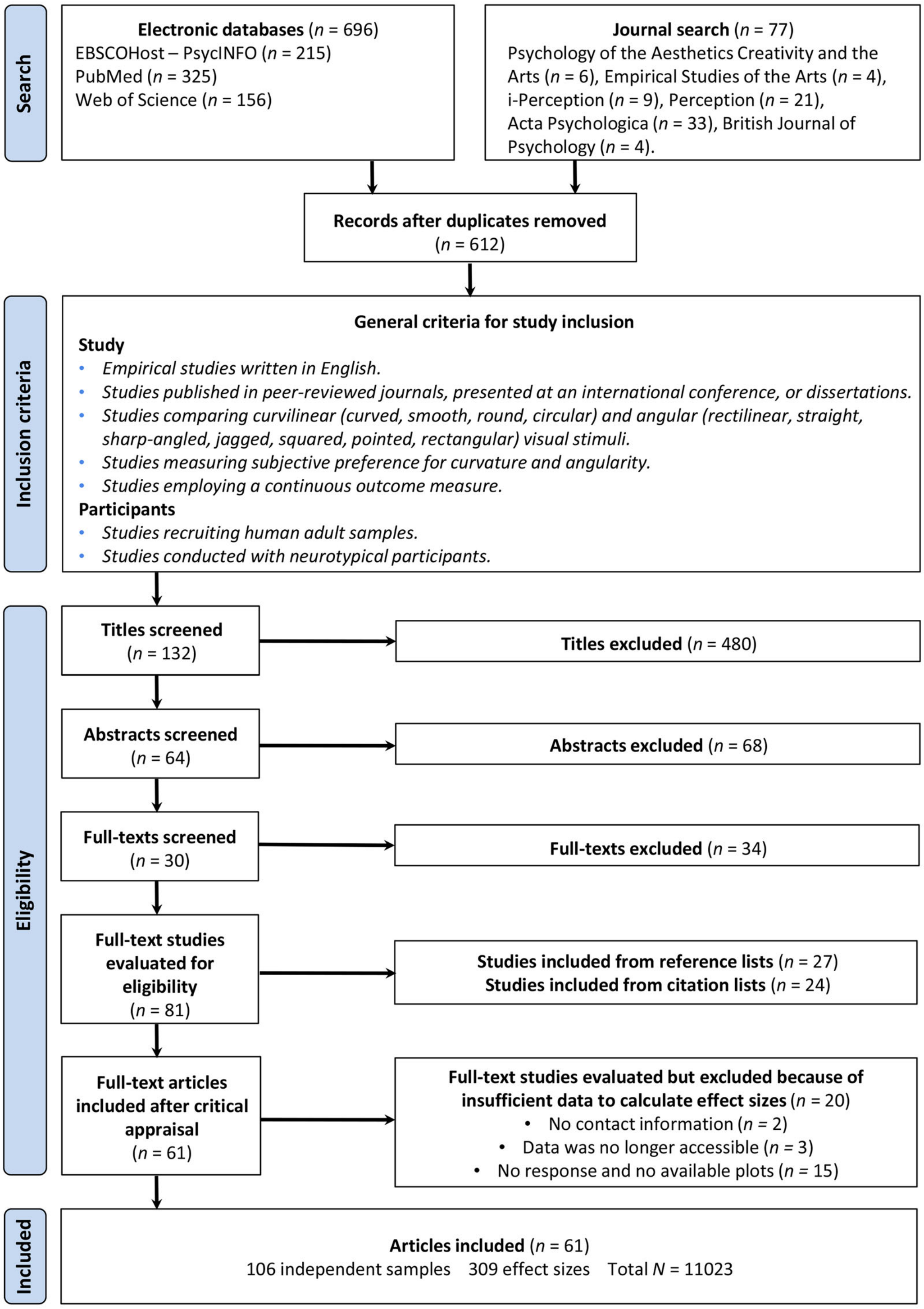

FIGURE 1 PRISMA flow diagram for the inclusion process. A total of 61 records fulfilled the eligibility criteria.

Finally, a model with the effect sizes and variance estimates averaged across studies showed a similar effect as the original analysis ($g = 0.39$, $z = 5.42$, $p < 0.001$, 95% CI [0.25, 0.53]). Overall, these results suggest that there is a true effect of preference for curvature even when dependencies among effect sizes are accounted for.

When excluding influential cases based on Cook's distance (see Materials and Methods), the magnitude of preference for curvature was slightly smaller compared to the original analysis ($g = 0.33$, $t = 5.02$, $p < 0.001$, 95% CI [0.20, 0.46]). A second sensitivity analysis excluding effect sizes extracted from values represented in plots yielded a slightly larger effect compared to the original analysis ($g = 0.42$, $t = 6.60$, $p < 0.001$, 95% CI [0.30, 0.55]). Finally, a third sensitivity analysis excluding effect sizes from studies using real (three-dimensional) stimuli showed a similar effect size compared to the original analysis ($g = 0.36$, $t = 5.26$,

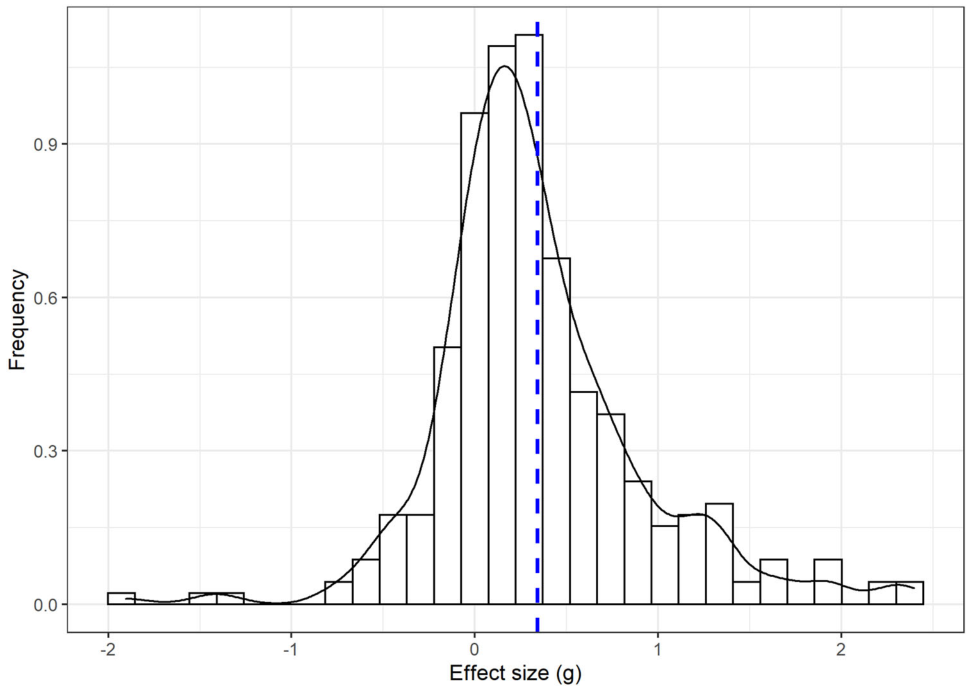

FIGURE 2 Histogram of the included effect sizes. The dashed line represents the mean value.

TABLE 1 Summary statistics of the included studies

N studies = 61	Mean	Median	SD	Minimum	Maximum
Effect size estimate (g)	0.34	0.24	0.57	−1.91	2.40
N samples = 106	Female	Male	Unknown	Minimum	Maximum
Participants	6018	4367	638	12	2006

Note: Female: 54.59%, Male: 39.62%, and Unknown: 5.79%.
Abbreviation: SD, standard deviation.

TABLE 2 Fixed effects and heterogeneity estimates from the three-level models and the two-level models

	Fixed-effect estimates			Heterogeneity estimates			
Models	g	SE	95% CI	$T^2_{level\ 2}$	$T^2_{level\ 3}$	$I^2_{level\ 2}$	$I^2_{level\ 3}$
Three-level	0.39 ***	0.07	0.25, 0.52	0.04	0.24	14.38	77.67
Without Level 2	0.39 ***	0.07	0.25, 0.52	0	0.27	0	91.76
Without Level 3	0.37 ***	0.05	0.27, 0.47	0.25	0	91.26	0

Abbreviations: CI, confidence interval; SE, standard error.
****p* < 0.001.

$p < 0.001$, 95% CI [0.22, 0.49]). Since none of these analyses revealed any major deviation from the original analysis, we retained all studies in our further exploration of the dataset.

We conducted a variant of the Egger regression test, incorporating a multi-level meta-analysis, to assess funnel plot asymmetry or small-study effects while handling dependencies among effect sizes.[95] Results indicated no evidence of a small-study bias ($\beta = 0.70$, $p = 0.32$). Figure 3 shows a contour-enhanced funnel plot of the relationship between effect size and standard error. Contour-enhanced funnel plots make it easier to assess whether possible missing effect sizes correspond to areas of low or high statistical significance.[96] When missing studies correspond to areas of low statistical significance, funnel plot asymmetry may be caused by publication bias. Conversely, when missing studies correspond to areas of high statistical significance, the asymmetry is less likely to be caused by publication bias. Here, visual inspection suggested that some effect sizes with small standard errors are dispersed far from the mean, especially toward the right-side area. However, the plot does not indicate asymmetry, nor does it indicate evidence of publication bias as effect sizes are represented in both areas of low and high significance.

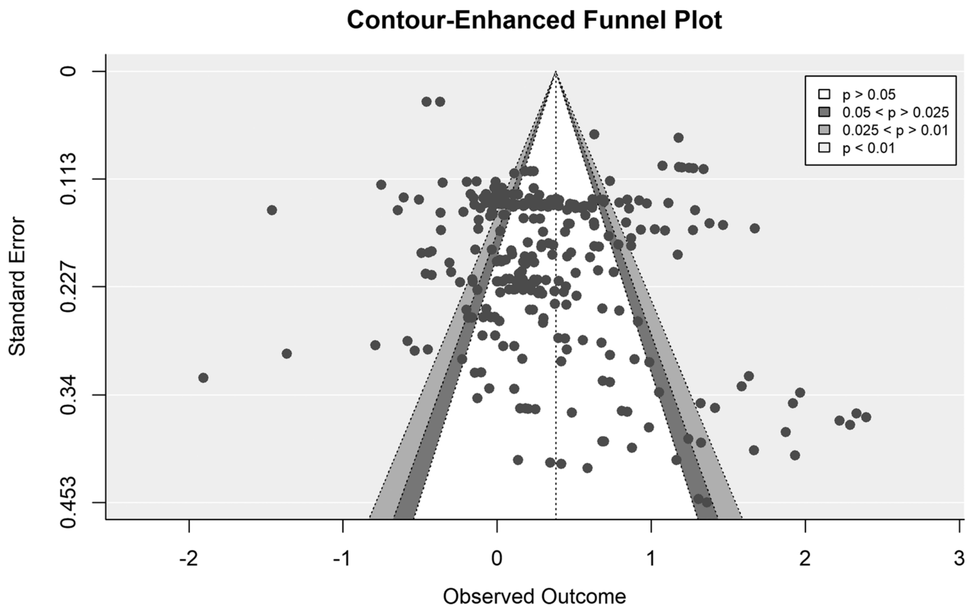

FIGURE 3 Contour-enhanced funnel plot of the effect sizes included in the meta-analysis. Each dot represents an effect size. The vertical line represents the overall effect of preference for curvature. Within the funnel plot, the white area shows nonsignificant effect sizes. The dark gray area shows significant effect sizes with a *p*-value between 0.05 and 0.025. The light gray area shows effect sizes with a *p*-value between 0.025 and 0.01. The area out of the funnel shows effect sizes with a *p*-value smaller than 0.01.

Moderator analyses

The effect of preference for curvature coexists with substantial between-study heterogeneity variance ($I^2_{\text{level 3}}$ = 77.67%). We ran moderator analyses with *task* (artistic, economic, semantic, hedonic, and magnetic), *stimulus type* (object, meaningless, spatial design, and symbolic design), *presentation time* (limited vs. unlimited), *measure* (continuous vs. continuous dichotomous), and *expertise* (experts, quasi-experts, and nonexperts) as variables, in order to ascertain if these conditions account for the variability among effect sizes (see Materials and Methods for further information on how these factors were defined).

The effect of task was significant, $Q(4) = 23.42$, $p < 0.001$. The magnitude of preference for curvature was moderate-to-large with the semantic ($g = 0.56$, $t = 7.05$, $p < 0.001$, 95% CI [0.40, 0.71], $k = 35$) task. In turn, the effect was moderate with the hedonic ($g = 0.39$, $t = 5.55$, $p < 0.001$, 95% CI [0.25, 0.52], $k = 184$) task, and small-to-moderate with the artistic ($g = 0.36$, $t = 3.75$, $p < 0.001$, 95% CI [0.17, 0.55], $k = 42$) and economic ($g = 0.34$, $t = 4.28$, $p < 0.001$, 95% CI [0.18, 0.49], $k = 31$) tasks. Lastly, the effect was small with the magnetic ($g = 0.22$, $t = 2.30$, $p = 0.022$, 95% CI [0.032, 0.41], $k = 17$) task (Figure 4). Pairwise comparisons showed that the effect was significantly larger with the semantic task than with the magnetic ($g_{diff} = 0.33$, 95% CI [0.16, 0.50], $p < 0.001$), economic ($g_{diff} = 0.22$, 95% CI [0.11, 0.33], $p < 0.001$), artistic ($g_{diff} = 0.19$, 95% CI [0.028, 0.36], $p = 0.022$), and hedonic ($g_{diff} = 0.17$, 95% CI [0.078, 0.26], $p < 0.001$) tasks. Similarly, the effect was larger with the hedonic task than with the magnetic task ($g_{diff} = 0.16$, 95% CI [0.011, 0.31], $p = 0.035$).

The effect of stimulus type was also significant, $Q(3) = 12.52$, $p = 0.0058$. The magnitude of preference for curvature was moderate-to-large with meaningless ($g = 0.56$, $t = 5.78$, $p < 0.001$, 95% CI [0.37, 0.75], $k = 83$) stimuli and moderate with real ($g = 0.42$, $t = 4.34$, $p < 0.001$, 95% CI [0.23, 0.62], $k = 123$) stimuli. In contrast, the effect was small-to-moderate and nonsignificant with symbolic design ($g = 0.30$, $t = 1.69$, $p = 0.092$, $k = 30$), and small and nonsignificant with spatial design stimuli ($g = -0.04$, $t = 0.26$, $p = 0.80$, $k = 73$). Pairwise comparisons revealed that the effect with meaningless stimuli was significantly larger than the effect with spatial design stimuli ($g_{diff} = 0.52$, 95% CI [0.22, 0.82], $p < 0.001$). Similarly, the effect with real stimuli was larger than the effect with spatial design stimuli ($g_{diff} = 0.39$, 95% CI [0.062, 0.71], $p = 0.020$).

The effect of presentation time was also statistically significant, $Q(1) = 15.41$, $p < 0.001$. Preference for curvature was higher when stimuli were presented with limited display times ($g = 0.75$, $t = 6.45$, $p < 0.001$, 95% CI [0.52, 0.99], $k = 50$; i.e., from 84 to 7000 ms). In contrast, the effect was small-to-moderate with unlimited presentation times ($g = 0.32$, $t = 4.39$, $p < 0.001$, 95% CI [0.17, 0.46], $k = 259$; i.e., until response). To further examine the effect of presentation time on the cognitive processing of visual contour, we ran an additional model by considering presentation times below 1000 ms as a threshold for limited display times. In this case, the effect of presentation time did not reach statistical significance, $Q(1) = 1.95$, $p = 0.16$. However, results also revealed that the magnitude of preference for curvature was moderate-to-large with display times below or equal to 1000 ms ($g = 0.59$, $t = 3.68$, $p < 0.001$, 95% CI [0.27, 0.90], $k = 16$), while it was only moderate with display times above 1000 ms ($g = 0.37$, $t = 5.40$, $p < 0.001$, 95% CI [0.24, 0.51], $k = 293$).

We found no moderating effect of measure on curvature preference, $Q(1) = 1.63$, $p = 0.20$. The effect was significant with both continuous measures ($g = 0.41$, $t = 5.71$, $p < 0.001$, 95% CI [0.27, 0.55],

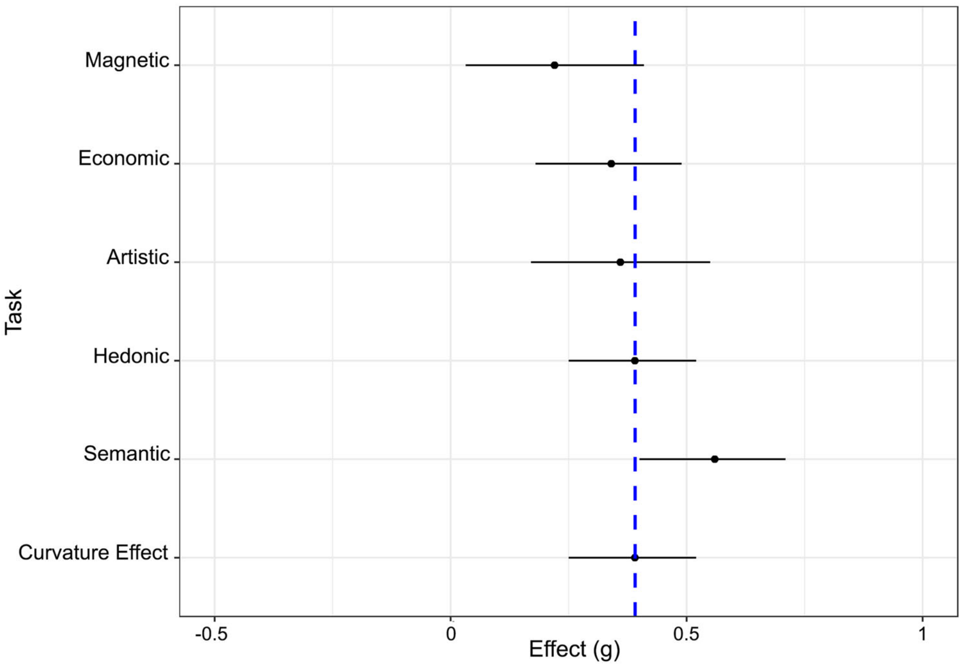

FIGURE 4 The effect of task on the magnitude of the effect of curvature. The dashed line represents the overall effect of preference for curvature. Error bars represent 95% CIs.
Abbreviation: CI, confidence interval.

$k = 275$) and continuous dichotomous measures ($g = 0.27$, $t = 2.45$, $p = 0.015$, 95% CI [0.054, 0.50], $k = 34$), but the difference between these measures was not significant. Finally, since there was no significant difference between experts and quasi-expert samples, ($g_{diff} = -0.13$, $p = 0.69$), these categories were combined ($k = 42$) and compared to the nonexpert samples ($k = 267$). Results revealed a significant effect of expertise, Q(1) = 4.25, $p = 0.039$. While the curvature effect was moderate and significant with nonexperts ($g = 0.40$, $t = 5.80$, $p < 0.001$, 95% CI [0.27, 0.54], $k = 267$), the effect was small and nonsignificant with experts ($g = 0.13$, $t = 0.94$, $p = 0.35$, $k = 42$). From the studies working with experts, a single study recruited dental health experts and provided more than half of the expert records.[65] In contrast, the other studies focused on experts in architecture, design, and the arts. Therefore, we repeated the model focusing on the comparison among these last experts and nonexperts. In this case, the effect of expertise was also significant, Q(1) = 8.35, $p = 0.0039$, such that it was larger with nonexperts ($g = 0.41$, 95% CI [0.27, 0.55], $p < 0.001$, $k = 267$) than with experts on architecture, design, and the arts ($g = -0.034$, $p = 0.83$, $k = 18$).

Exploratory analyses

In addition to the preregistered protocol, we conducted some additional exploratory analyses. The moderating effect of the year of publication on curvature preference was not significant, Q(1) = 0.18, $p = 0.67$.[a] Similarly, the moderating effect of data collection procedure was not significant, Q(1) = 0.18, $p = 0.67$. The magnitude of preference for curvature was similar when the task was carried out in person ($g = 0.40$, $t = 5.40$, $p < 0.001$, 95% CI [0.25, 0.54], $k = 226$) as when it was carried out online ($g = 0.34$, $t = 2.72$, $p = 0.0069$, 95% CI [0.094, 0.59], $k = 83$). Furthermore, the magnitude of the effect was similar regardless of whether studies used paper-based tasks ($g = 0.39$, $t = 2.75$, $p = 0.0064$, 95% CI [0.11, 0.67], $k = 73$), computer-based tasks ($g = 0.34$, $t = 4.16$, $p < 0.001$, 95% CI [0.18, 0.50], $k = 131$), or web-based tasks ($g = 0.34$, $t = 2.65$, $p = 0.0084$, 95% CI [0.087, 0.59], $k = 80$). Lastly, the moderating effect of verbal terminology was not significant, Q(14) = 19.23, $p = 0.16$. The magnitude of preference for curvature was large with the terminology “curvilinear/rectilinear” ($g = 0.90$, $t = 4.48$, $p < 0.001$, 95% CI [0.51, 1.30], $k = 30$), whereas the magnitude of the effect was moderate with the terminology “round/angular” ($g = 0.43$, $t = 2.93$, $p = 0.0037$, 95% CI [0.14, 0.73], $k = 52$), and small-to-moderate with the terminology “curved/sharp,” ($g = 0.40$, $t = 2.62$, $p = 0.0092$, 95% CI [0.10, 0.71], $k = 43$) and “curved/angular” ($g = 0.37$, $t = 2.54$, $p = 0.012$, 95% CI [0.083, 0.66], $k = 73$).

[a] This analysis, intended to test for the possible effects of societal and cultural changes in taste, was suggested by Melanie Wald–Fuhrmann.

DISCUSSION

This meta-analysis was conducted to compute the average effect size for visual curvature preference. The results of a three-level random effects model revealed a Hedges’ g of 0.39—consistent with a medium effect size. However, they also revealed substantial between-study heterogeneity variance, consistent with moderation effects associated with presentation time, stimulus type, expertise, and task. This finding suggests that while visual objects with a curvilinear contour are preferred to objects with an angular contour in many evaluative contexts, they are not preferred to the same extent in all contexts. Below, we discuss the possible reasons why a preference for curvature is modulated by such factors.

Presentation time

Curvature was preferred more in evaluative contexts where responses were collected with limited presentation times than in evaluative contexts with unlimited presentation times. This observation suggests that preference for curvature emerges rather rapidly when viewing stimuli and that additional time is likely to engage top-down processes that could serve to attenuate the effect. Basic sensory and perceptual aspects of stimuli (e.g., symmetry, contour, etc.) exert their effects as a consequence of rapid perceptual responses in early, posterior parts of the ventral visual stream, with top-down processes representing semantics, and content occurring at later stages of the ventral visual processing pathway.[35,81,97] This hypothesis is consistent with the evolutionary hypothesis that contour serves as a form of fast input to circuits that determine the relevance of visual stimuli to survival; in order for organisms to respond rapidly to potential threats, perceptual representations of angularity and curvature are relayed quickly and directly to mesocorticolimbic structures where appropriate appetitive or defensive actions can be initiated in a matter of microseconds.[98]

However, visual perception is not simply a matter of sequential forward projection of information driven by stimulation of sensory receptors.[99–101] Expectations derived from previous experiences or task conditions are also known to modulate the way stimuli are computed by neurons involved in visual perception.[102,103] Experiments have found such expectations to influence how pleasurable an object is experienced to be,[104,105] with prior preferences biasing evoked neural activity in both perceptual and valuation regions.[106–108] It is, therefore, conceivable that a higher preference for curvilinear stimuli observed during evaluation events where stimuli are presented only for a brief time period reflect predictive coding as much as bottom-up driven processing. It will be important for future studies to clarify how computational mechanisms involved in visual liking unfold over different temporal time scales.

Stimulus type

Preference for curvature was also shown to be stronger for real and imaginary objects than for spatial designs and/or symbols. This observation could be explained by several factors. In terms of their affordances—defined as the actions or uses that they enable[109]—contour might be a more salient and relevant feature for objects (whether real or imaginary) than spaces or symbols. In other words, whether an object's form is curvilinear or angular might play a more important role in our choices to interact with them than might be the case with spaces and symbols. Another possibility might be mere exposure.[110] Specifically, we may encounter curvilinear and angular objects more frequently than we do curvilinear and angular spaces and symbols, and as such develop greater levels of processing fluency in evaluating them.[111,112] In this sense, the larger effect size for contour for objects compared to spaces and symbols could reflect our greater ability to distill and appraise the sensory and perceptual features of the former type of stimuli. Indeed, the same could be true for imaginary objects given that they too represent object-like features when used as stimuli in experimental studies, including boundaries, contrast, and symmetry, among others.

Expertise

Participants' expertise also affected preference for curvature, with a stronger effect in studies recruiting nonexpert than expert participants. However, this result should be interpreted carefully because out of the 61 studies included in the meta-analysis, only six recruited expert participants. Moreover, while our findings suggest that expertise modulates people's sensitivity and preference for curvature, it is likely that this is true only when the evaluated objects are specific to the participant's field of expertise.[32]

Task

Finally, evaluative task conditions also moderated the size of the effect of curvature. Recall that across studies researchers had asked participants to evaluate curvilinear and angular stimuli using diverse evaluative anchors (e.g., approach/avoidance, attractiveness, beauty, comfortableness, valence, liking, price expectation, wanting, etc.). Different evaluative anchors evoke computational mechanisms associated with hedonic valuation to different degrees,[113,114] presumably because evaluative anchors, such as *beauty* or *liking*, prompt participants to evaluate stimuli according to different evaluative target dimensions.[115,116]

To examine in greater detail how the use of different evaluative anchors affects curvature preference, we grouped the included tasks into five bins (semantic, artistic, economic, magnetic, and hedonic). The effect of preference for curvature was largest for evaluations that used semantic tasks, registering a significant difference compared to the other tasks. Semantic tasks were those that involved categorizations based on the semantic differential scales of the evaluative dimension used to measure the value of an object,[63] such as good/bad, positive/negative, aggressive/peaceful, and so on. This effect might indicate that contour could have a strong semantic association with the dimensions under consideration.[12,19] In other words, there could be a strong semantic association between curvilinear and angular forms and the opposing poles of those dimensions. Another possibility might be that compared to semantic tasks, other task conditions bring additional contextual and individual-differences factors into play that could serve to weaken the effect of contour on choice. For example, judging whether a face is attractive or not (i.e., a hedonic task) necessitates that the participant activates a mental representation of attractiveness which might vary considerably across individuals. In turn, this variation might interact with the task. Similarly, deciding how much one would like to pay for an object (i.e., an economic task) requires the participant to activate a mental representation of monetary value which might again vary across individuals based on background factors, such as socioeconomic status. This line of reasoning suggests that one is more likely to observe a strong preference for curvature if the evaluative task involves a relatively direct evaluation of the stimulus along a dimension used to measure its value.

What is the cause of curvature preference?

Together, our results demonstrate that preference for visual curvature is influenced by factors other than perceptual information signaling contour shape. This finding highlights the need for future research that describes in more detail the computational mechanisms that determine individual liking responses to visual objects with curvilinear contour. The current consensus among neuroscientists holds that liking and disliking for sensory stimuli occur as a function of information transfer from sensory systems to the mesocorticolimbic reward circuit.[117,118] Liking and disliking outcomes appear to be determined by the state and intensity of pleasure and displeasure elicited in response to a given stimulus.[119,120] The manner in which nuclei that encode pleasure and displeasure become engaged by information from sensory systems is often modulated by individual differences in how brains are functionally and structurally organized, as well as by the contextual conditions under which the stimulus is being appraised.[115,121] We believe that a similar process may be at play for preference for curvature in the form of a loop that connects the sensory cortices that exhibit sensitivity to the perception of contour to regions within the brain that underlie the valuation of stimuli. Consistent with this idea, several meta-analyses have revealed that the aesthetic evaluation of objects in the visual domain engages regions within sensory and perceptual cortices, as well as regions of the brain that underlie the processing of reward.[122–124] What remains unknown are the specific mechanisms that underlie the transfer of information from the sensory and perceptual cortices to the reward regions, which eventually leads to an evaluative appraisal of the object under consideration.

A recent study by Yue et al.[125] has made important strides in this regard by demonstrating that patches of neurons located in bilateral V3 and V4, as well as in the lateral occipitotemporal cortex (LOC) and fusiform gyrus (FG), respond preferentially to curvilinear contour. This result suggests that both regions in the earlier and later parts of the ventral visual system are involved in representing how curvilinear or angular an object's contour is perceived to be. However, it remains unknown how neural activity evoked by this network of neurons affects activity in other neural systems, including the reward circuitry. Fortuitously, analytic methods involving fMRI data (e.g., dynamic causal modeling) exist that can test how patterns of connectivity between V3, V4, LOC, FG, and other regions of interest affect liking outcomes for stimuli varying in contour shape, and we expect this endeavor to be a likely focus of research in neuroscientific studies on the effect of contour on hedonic valuation.

Limitations and future directions

We focused only on studies employing continuous measures (i.e., rating scales or two-alternative responses) and were not able to compute the effect sizes from all the studies meeting eligibility criteria because of insufficient data for their calculation. When we computed the average effect size of the smaller set of studies employing dependent dichotomous measures,[21,30,33,40,47–53] results indicated an odds ratio of 2.13—consistent with a small effect size.[126] Nevertheless, this meta-analysis comprises a relevant set of studies that investigated the effect of visual curvature under various conditions providing an estimate of the true effect of preference for visual curvature.

Our findings also provide some implications for applied research on contour preference. As reviewed here, many studies from multidisciplinary fields have investigated preference for visual curvature with an increasing number of experiments from applied domains, such as advertising, marketing, packaging, interior design, and security perception, among others.[10] Thus, these domains could benefit from our results by targeting people's preferences or environmental perceptions. For example, marketers could employ specific evaluative anchors to advertise hedonic or utilitarian products with different contour types; or artists could gain insights into how the audience's shape preferences may vary depending on their previous experience in design, architecture, or the arts. Moreover, our findings could also benefit the design of ecological and friendlier environments, which may foster people's well-being and inclusiveness.[37] Importantly, this meta-analysis also has isolated conditions under which the strength of preference for visual curvature is likely to be maximal. Thus, future research in vision and visual neuroscience could benefit by establishing an empirical benchmark for the strength of this effect (i.e., Hedges' g of 0.39) before examining its strength based on more rigorous manipulations.

Our moderator analyses demonstrated the presence of notable variance that is left unaccounted for, which could be explained by other variables not considered in our analysis.[127] Part of this difficulty lies in the heterogeneity with which the same core constructs have been conceptualized and measured in this literature. For example, researchers have long suspected that relevant domain expertise might impact one's sensitivity to and preference for curvature. However, whereas some studies have evaluated the influence of expertise by recruiting expert and nonexpert participants,[13,34,37,65,79,128] others have assessed expertise as a continuous variable/trait via self-reported questionnaires.[14,15,32,36,50,51,81,90,129] Furthermore, when recruiting experts, some studies have recruited true experts (e.g., Ref. 34), whereas others have relied on quasi-experts (e.g., Ref. 37)—despite well-established differences between true experts (i.e., professionals with formal training working in a field) and quasi-experts (i.e., apprentices or graduate students in a field) in relative familiarity with a domain. We suspect that future reviews and meta-analyses of this growing literature will examine the literature in other ways than we have here, perhaps with sharper conceptual and operational definitions of key constructs under investigation, including expertise.

We also believe that the next frontier in this field will likely involve two advances. First, currently, there is no computationally derived consensus measure for quantifying the degree of curvature involving visual stimuli. The discovery of such a mathematical algorithm will be useful as a standardization tool, enabling comparison of what is meant by curvature across stimulus categories (e.g., objects, scenes, and artworks). Second, the neurobiological mechanisms that give rise to a preference for contour have yet to be unearthed. Building on recent research that has revealed regions in the occipital and temporal cortices that are sensitive to contour, we believe that the next frontier in this line of research involves identifying the neurobiological mechanisms that give rise to a preference for contour—connecting sensory perception to hedonic valuation.

CONCLUSIONS

Substantial empirical evidence gathered over the last century shows that people prefer curvature in the visual domain across many tasks and contexts. Because preference for curvature has also been documented across ages, cultures, and species, it has come to be viewed as potentially a universal phenomenon in the visual domain. On the other hand, it is also clear that the occurrence and strength of preference for curvature are influenced by individual differences and contextual factors. Here, we conducted a meta-analysis of the empirical research on contour to calculate the strength of the effect of preference for curvature in the visual domain. The results of a three-level random effects model revealed a Hedges' g of 0.39—consistent with a medium effect size. This effect was moderated by presentation time, stimulus type, task, and expertise. Together, our results show that people's preference for curvature in the visual domain is general and common, though not universal and invariant.

AUTHOR CONTRIBUTIONS

O.V., M.S., M.N., P.J.S., and E.M. conceived the idea. E.G.C., G.B.C., and E.M. designed the study protocol and the data analysis plan. E.G.C., O.V., G.B.C., and E.M. performed the literature searches. E.G.C., G.B.C., and E.M. screened the studies and analyzed the data. E.G.C., O.V., M.S., and E.M. interpreted the results. E.G.C., O.V., M.S., M.N., and P.J.S. drafted the manuscript. All authors edited, revised, and approved the final version of the manuscript.

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COMPETING INTERESTS

The authors declare that there are no competing interests.

ORCID

Erick G. Chuquichambi https://orcid.org/0000-0001-5389-283X
Martin Skov https://orcid.org/0000-0002-4895-4802

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3.2. Circles are detected faster than downward-pointing triangles in a speeded response task

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Circles Are Detected Faster Than Downward-Pointing Triangles in a Speeded Response Task

Erick G. Chuquichambi and Carlos Rey
University of the Balearic Islands, Spain

Rosana Llames
University of Seville, Spain

Juan T. Escudero, Alejandro Dorado and Enric Munar
University of the Balearic Islands, Spain

Abstract

Simple geometric shapes are associated with facial emotional expressions. According to previous research, a downward-pointing triangle conveys the threatening perception of an angry facial expression, and a circle conveys the pleasant perception of a happy facial expression. Some studies showed that downward-pointing triangles have the advantage to capture attention faster than circles. Other studies proposed that curvature enhances visual detection and guides attention. We tested a downward-pointing triangle and a circle as target stimuli for a speeded response task. The distractors were two stimuli that resulted from the mixture of both targets to control for low-level features' balanced presentation. We used 3×3, 4×4, and 5×5 matrices to test whether these shapes led attention to an efficient response. In Experiment 1, participants responded faster to the circle than to the downward-pointing triangle. They also responded slower to both targets as the number of distractors increased. In Experiment 2, we replicated the main findings of Experiment 1. Overall, the circle was detected faster than the downward-pointing triangle with small matrices, but this difference decreased as the matrix size increased. We suggest that circles capture attention faster because of the influence of low-level features, that is, curvature in this case.

Corresponding author:
Erick G. Chuquichambi, Human Evolution and Cognition Group (EvoCog), Faculty of Psychology, University of the Balearic Islands, Campus. Ctra. Valldemossa Km 7'5, 07122 Palma, Balearic Islands, Spain.
Email: erik.chuquichambi@uib.es

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shape, low-level features, perception, speeded response task, curvature

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Angry faces would capture our attention faster according to an anger superiority effect (Dickins & Lipp, 2014; Fox et al., 2000; Hansen & Hansen, 1988; Pinkham et al., 2010). Happy faces would capture our attention faster according to a happiness superiority effect (Becker et al., 2011; Calvo & Nummenmaa, 2008; Craig et al., 2014). Savage et al. (2013) found that previous anger and happiness superiority effects emerged depending on the specific face database used. They indicated the unbalanced presentation of low-level features between stimulus sets as the cause of either one of the two effects, but this imbalance was sometimes also found within the same stimulus set. The low-level features that configure the stimulus sets must be balanced. Therefore, angry and happy superiority effects may not be based on pure facial emotional content, but rather on the role of low-level features that compose the face (Coelho et al., 2011; Savage et al., 2013; Wolfe, 2018). These low-level features would guide our attention (Wolfe, 2010, 2018; Wolfe & Utochkin, 2019).

According to Larson et al. (2007, 2009, 2012) and Lobue and Larson (2010), we can evoke emotional meaning with simple nonrepresentational geometric shapes underlying facial expressions. A downward-pointing triangle would convey the threat of an angry facial expression, and a circle would convey the pleasantness of a happy facial expression (Aronoff, 2006; Aronoff et al., 1988, 1992). Larson et al. (2007) hypothesized that downward-pointing triangles capture attention rapidly because they elicit an adaptive perception of threat. They used 4×4 matrices in different experiments in which participants had to determine whether a target stimulus was present for each matrix. They found that downward-pointing triangles were detected slightly faster than circles in one experiment. However, they found no differences in another experiment. They concluded that the downward-pointing triangle captured attention faster than the circle. They suggested that downward-pointing triangles are similar to the geometric configuration of angry faces and that these shapes activate the amygdala (Larson et al., 2009), a neural structure related to the detection of potential threat.

According to Wolfe and Utochkin (2019), low-level visual features guide our attention efficiently. Simple shapes may elicit faster visual detection because of the advantage of some of these features to capture attention. However, Wolfe (2018) suggested that threat perception was a probable nonguiding attentional attribute if other low-level visual features were controlled for. He proposed several guiding attentional attributes such as line termination, closure, topological properties, or even curvature. Curvature has been suggested as a basic feature for visual search (Treisman & Gormican, 1988; Wolfe et al., 1992), and to elicit a quick visual detection over rectilinear shapes (LoBue, 2014; Lobue & Deloache, 2010). Given that a triangle is a sharp-angled and rectilinear shape, whereas a circle is a completely curved shape, the proposal that curvature is a guiding attentional attribute does not match the findings reported by Larson et al. (2007). Moreover, in a study about speed of processing shape, Bertamini et al. (2019) reported four experiments using abstract shapes, smoothed (curved) and angular. In the four tasks, responses for curved shapes were faster. According to the authors, there was evidence that smoothed shapes with continuous change in curvature along the contour are processed more efficiently, and they tend to be classified as targets.

From the studies about the anger versus happiness superiority effects, Frischen et al. (2008) proposed that the set size should be varied to assess linear search slopes to calculate search efficiency. Savage et al. (2013) also indicated that the procedure that uses the same stimuli as distractor and target confounds the effects because we do not know whether the speed is a consequence of the target processing or the distractor processing. Larson et al. (2007) used triangles and circles as both target and distractor stimuli. Interestingly, participants responded faster to only circle distractor matrices than to only triangle distractor matrices. Therefore, it is difficult to know whether the reported superiority of the downward-pointing triangle was due to the targets or to the distractors.

Our study aims to shed light on the apparent contradiction between the results of Larson et al. (2007) that downward-pointing triangles are detected faster than circles and the proposal that curvature is a guiding attentional attribute (Wolfe, 2018) and is processed more efficiently (Bertamini et al., 2019). In two experiments, we examined whether downward-pointing triangles or circles capture attention faster when distractors are different from both targets and the matrix size is varied. We designed a similar speeded response task to the Larson's et al. (2007) where participants had to detect the presence of a target stimulus (either the downward-pointing triangle or the circle) or its absence (matrices with only distractors) in matrices with different number of elements. As the triangle and the circle were the target stimuli, we used two different distractor stimuli. The distractors resulted from the mixture of the two target stimuli: a half-circle and a half downward-pointing triangle. The combination of the distractor stimuli controlled for target stimulus similarity and balanced presentation of low-level features. We tried to ensure that the faster visual response was due to the target stimulus. We also examined whether the downward-pointing triangle or the circle led to a fast and accurate response. A fast and accurate visual response for a target stimulus among different matrix sizes would suggest that the low-level features of that shape guide attention (Wolfe & Utochkin, 2019). We hypothesized that circles would capture attention faster than downward-pointing triangles (LoBue, 2014; Lobue & Deloache, 2010; Treisman & Gormican, 1988; Wolfe, 1998, 2018; Wolfe et al., 1992).

Experiment 1

Methods

Participants. Larson et al. (2007) reported a large effect size of the matrix factor (downward-pointing triangle target, circle target, all downward-pointing triangles, and all circles), using eta-squared ($\eta^2 > .25$). Based on a statistical power of .95, and an alpha error of .05, we calculated our sample size according to both a large and medium effect size. It resulted in a sample size of 18 participants for a large effect and 40 participants for a medium effect. Thus, 57 undergraduate students (11 male) from the University of the Balearic Islands took part in the experiment in exchange for course credits ($M_{\text{age}} = 20.46$; $SD_{\text{age}} = 5.28$). All participants reported having normal or corrected-to-normal vision and provided written consent before the experiment. The study received ethical approval from the Committee for Ethics in Research of the Balearic Islands (IB 3828/19 PI), and it was conducted following the Declaration of Helsinki (2008).

Materials. A circle and a downward-pointing triangle were created as the target stimuli. We combined the two targets to create the distractor stimuli: a half-circle and a half-downward-pointing triangle. The combination of the distractors controlled for target stimulus similarity and balanced presentation of low-level features. Two distractors (Distractor 1 and

Distractor 2) were created, changing the sides of the two halves (i.e., the half-circle either on the left or on the right) to control for the presentation of the half sides. Distractor 1 or "Circangle" had a half-circle on the left and a half-triangle on the right, whereas Distractor 2 or "Tricircle" had a half-triangle on the left and a half-circle on the right. The four figures were 91 pixels high and 93 pixels wide. They were created using Adobe Photoshop CS6 (Figure 1).

We arranged the geometric shapes into matrices. The task was designed using OpenSesame 3.2 software (Mathôt et al., 2012). There were six matrix types: a circle target surrounded by Circangle Distractors, a circle target surrounded by Tricircle Distractors, a downward-pointing triangle surrounded by Circangle Distractors, a downward-pointing triangle surrounded by Tricircle Distractors, a matrix with only Circangle Distractors, and a matrix with only Tricircle Distractors. We used three matrix sizes in which the geometric shapes were equally separated: 3×3 (411 pixels high $\times$ 414 pixels wide), 4×4 (571×574 pixels), and 5×5 (731×734 pixels; Figure 2).

Participants carried out the task using individual computers in isolated cabins. The distance between the participant and the computer screen was 45 cm. Computers were equipped with Intel i5 processors and 21-inch screens set at $1{,}920 \times 1{,}080$ pixels resolution and 60 Hz.

Procedure. We organized the speeded response task in three blocks: a 3×3 matrix size block, a 4×4 matrix size block, and a 5×5 matrix size block. Each block was separated into two subblocks. Circangle Distractor was used in one subblock, and Tricircle Distractor was used in the other subblock. In each subblock, three matrix types were randomly presented.

Figure 1. Simple Geometric Shapes.
C represents the circle shape; T represents the downward-pointing triangle shape; D1 represents the Circangle Distractor; and D2 represents the Tricircle Distractor.

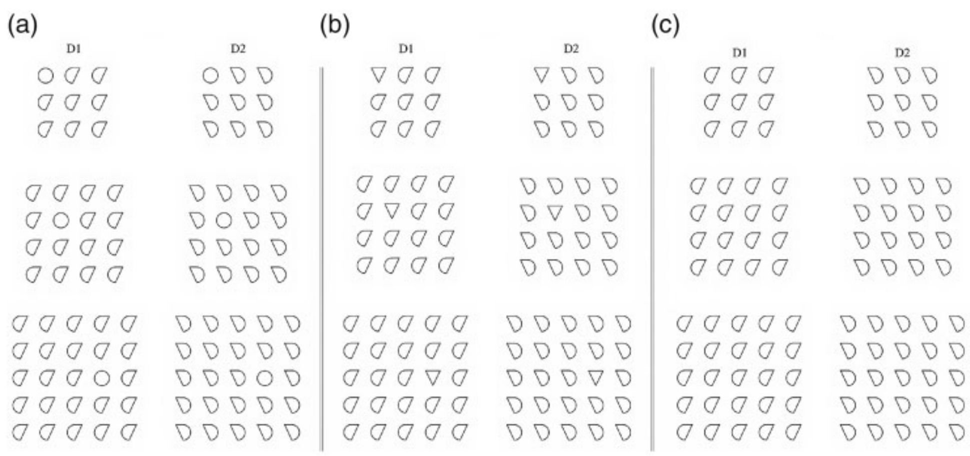

Figure 2. Examples of the Six Matrix Types and the Three Matrix Sizes.
(A) Circle target matrices; (B) Downward-pointing triangle matrices; and (C) Distractor matrices. From top to bottom: 3×3, 4×4, and 5×5 matrix sizes. The task was structured in three blocks regarding the three matrix sizes. In each block, Circangle and Tricircle Distractors were separated into two subblocks.

That is, the first subblock consisted of matrices with a circle target surrounded by Circangles, matrices with a downward-pointing triangle surrounded by Circangles, and matrices with only Circangles, whereas the second subblock consisted of the same matrix types with Tricircle Distractors. Thus, we controlled for the influence of the change of the distractor while participants performed the task (Frischen et al., 2008).

Participants carried out 400 experimental trials: 72 trials in the 3×3 block, 128 trials in the 4×4 block, and 200 trials in the 5×5 block. We used a different number of trials per block because the target was presented once in each matrix position. In each block, there was the same number of matrices with and without targets. There were also eight practice trials at the beginning of the task.

Participants received verbal instructions before starting the session and written instructions before the task. They were informed that geometric shapes arranged in matrices would be presented on the screen. Some of the matrices would all have the same geometric shapes, but others would have a different geometric shape from the others. Their task was to press an "equal" key when all the matrices had the same geometric shapes and a "not equal" key when the matrix had one geometric shape different from the others. They had to respond as fast as they could.

Each trial began with a central fixation cross presented for 500 ms, followed by a white screen for 100 ms. Then, a matrix was presented in the center of the screen until participants responded or for a maximum of 2,000 ms. We counterbalanced block sequence, subblock sequence, and keys for response: "equal" and "not equal," left-side or right-side. Trials were randomized. The experiment took about 25 minutes.

Analysis. We defined errors as incorrect responses or nonresponses for the 2,000-ms stimulus presentation time. Anticipated responses were defined as faster than 200 ms. From 57 participants, we collected 22,800 trials. One participant was eliminated because of an error rate greater than 25%. Delayed (98) and anticipated (3) responses were excluded from the trial set. A total of 575 trials were eliminated because of incorrect responses. Also, 329 trials were eliminated because of statistical cleaning (extreme values), using the box plot figures. A total of 21,395 trials from 56 participants remained for the analysis of response time (RT) averages.

Results

Analyses were conducted using SPSS 25.0.0 (SPSS Inc., Chicago, IL, USA) and R environment for statistical computing (R Core Team, 2019) with an alpha level of .05. Post hoc tests used Bonferroni correction. Confidence intervals (CIs) for effect sizes were calculated using an ad hoc script (http://daniellakens.blogspot.com.es/2014/06/calculating-confidence-intervals-for.html), ascertaining the obtained values with the "MBESS" package from the R statistical software. First, we carried out a five-factor mixed analysis of variance (ANOVA) on RT with Target (circle and triangle), Matrix (3×3, 4×4 and 5×5) and Distractor (Circangle and Tricircle) as within-subject factors. Block sequence (i.e., random sequence of 3×3, 4×4 and 5×5 blocks) and subblock sequence (i.e., random sequence of distractors) were included as between-subject factors. The effects of block sequence, $F(5, 55) = .6$, $p = .7$, $\eta_p^2 = .06$, 90% CI [0, 0.08], and subblock sequence, $F(1, 55) = 1.4$, $p = .24$, $\eta_p^2 = .026$, 90% CI [0, 0.12], were nonsignificant. Hence, we conducted a three-factor repeated-measures ANOVA on RT averages with Target, Matrix, and Distractor as within-subject factors.

Results yielded a significant main effect of Target, $F(1, 55) = 7.63$, $p = .008$, $\eta_p^2 = 0.12$, 90% CI [0.019, 0.26]. Participant responses were faster for the matrices with the circle ($M = 668$ ms, $SD = 87$) rather than the downward-pointing triangle ($M = 680$ ms, $SD = 90$). This result suggests that they detected circles faster than triangles. Matrix also showed a significant main effect, $F(2, 55) = 41.16$, $p < .001$, $\eta_p^2 = .43$, 90% CI [0.44, 0.68]. Bonferroni-corrected comparisons showed that participants responded significantly faster to the 3 × 3 matrices ($M = 638$ ms, $SD = 89$) than to the 4 × 4 matrices ($M = 666$ ms, $SD = 87$), $t(55) = -3.4$, $p = .004$, $g = -.32$, 95% CI [–48.31, –7.6], and also faster than to the 5 × 5 matrices ($M = 716$ ms, $SD = 90$), $t(55) = -9.6$, $p < .001$, $g = -.87$, 95% CI [–97.64, –57.6]. They also responded faster to the 4 × 4 matrices than to the 5 × 5 matrices, $t(55) = -5.2$, $p < .001$, $g = -.56$, 95% CI [–73.3, –26].

Target × Matrix interaction was significant, $F(2, 55) = 5.73$, $p = .004$, $\eta_p^2 = .09$, 90% CI [0.03, 0.3]. As Figure 3 shows, RTs in the 4 × 4 and 5 × 5 matrices were quite similar for the matrices with the circle and triangle targets. However, the difference between circles ($M = 623$ ms, $SD = 83$) and triangles ($M = 655$ ms, $SD = 95$) was significant in the 3 × 3 matrices, $t(55) = 4.36$, $p < .001$, $g = -.36$, 95% CI [–53.9, –10.14]. Due to this difference, we analyzed the data only considering the nine central positions (the ones corresponding to the 3 × 3 matrices) in the 5 × 5 matrices. In this case, there was no significant difference between participant responses for the matrices with the circle ($M = 671$ ms, $SD = 90$) and triangle targets ($M = 677$ ms, $SD = 87$) according to the Wilcoxon signed-rank test, $Z = 623.5$, $p = .16$, $r = .22$, 95% CI [–0.48, 0.08].

We also found a significant effect of Distractor, $F(1, 55) = 6.6$, $p = .013$, $\eta_p^2 = .11$, 90% CI [0.01, 0.25]. Participants responded faster to Tricircle matrices ($M = 666$ ms, $SD = 87$) than to Circangle matrices ($M = 680$ ms, $SD = 90$). However, none of the interactions related to Distractor was significant, either Target × Distractor, $F(1, 55) = 1.28$, $p = .26$, $\eta_p^2 = .02$, Matrix × Distractor, $F(1, 55) = 1.43$, $p = .24$, $\eta_p^2 = .02$, or the triple interaction, $F(1.76, 55) = .49$, $p = .6$, $\eta_p^2 = .009$.

Three linear regression analyses were carried out to examine the slope of the function relating RT to matrix size. We built a model for each type of matrix, that is, matrices with a circle, matrices with a triangle, and matrices with only distractors. In each model, RT was the dependent variable. Matrix size was the predictor variable with three levels: the number of items of the matrix (i.e., 9, 16, and 25). Results showed a significant linear relationship

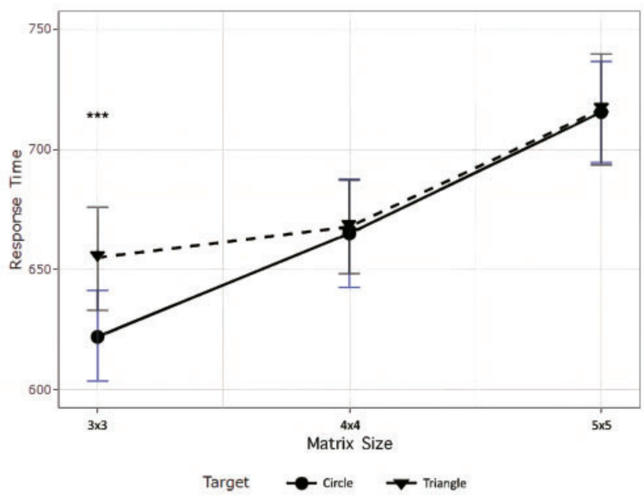

Figure 3. Experiment 1: Response Time According to Target × Matrix Size Interaction (***$p < .001$). Error bars represent 95% CI.

between RT and matrix size in the three regression analyses. With the circle as a target, we found a significant but weak relationship between the RT and the number of items in the matrix, $\beta = 5.34$, $t(166) = 5.12$, $p < .001$ ($R^2_{adj} = .13$). With the triangle as a target, we also found a significant and weak relationship between RT and the number of items, $\beta = 3.82$, $t(164) = 3.84$, $p < .001$ ($R^2_{adj} = .077$). Finally, with only distractors (target-absent matrices), the number of items was a significant predictor of slower RTs, $\beta = 13.04$, $t(162) = 8.05$, $p < .001$ ($R^2_{adj} = .28$).

We also conducted a three-factor repeated-measures ANOVA on accuracy. We defined accuracy as the proportion of the correct responses about the presence (matrices with a circle or a downward-pointing triangle) or absence (matrices with only distractors) of a target stimulus in the total number of trials. The ANOVA included Target (circle and triangle), Matrix (3×3, 4×4 and 5×5) and Distractor (Circangle and Tricircle) as within-subject factors. Target was nonsignificant, $F(1, 51) = 2.3$, $p = .13$, $\eta_p^2 = .04$, 90% CI [0, 0.16]. In contrast, matrix showed a significant main effect, $F(1.8, 51) = 4.45$, $p = .02$, $\eta_p^2 = .08$, 90% CI [0.012, 0.26]. Participants were less accurate with the 5×5 matrices ($M = .956$, $SD = .05$) than with the 4×4 ones ($M = .967$, $SD = .045$), $t(51) = 3.2$, $p = .007$, $g = -.23$, 95% CI [0.003, 0.024]. There were no significant difference between 5×5 matrices and 3×3 matrices ($M = .965$, $SD = .05$), $t(51) = 2$, $p = .27$, $g = .18$, 95% CI [–0.003, 0.025], nor between 4×4 matrices and 3×3 matrices, $t(51) = -.5$, $p = 1$, $g = .04$, 95% CI [0.003, 0.024]. Interestingly, the Target × Matrix interaction was significant, $F(1.7, 51) = 5.8$, $p = .007$, $\eta_p^2 = .1$, 95% CI [0.01, 0.32]. This effect was caused by the significant difference between circles ($M = .979$, $SD = .042$) and triangles ($M = .956$, $SD = .044$) in the 3×3 matrices, $t(51) = 3.66$, $p = .005$, $g = .53$, 95% CI [0.007, 0.04] (Figure 4). All other effects were nonsignificant.

Discussion

Experiment 1 showed that participants responded to the matrices with a circle faster than the matrices with a downward-pointing triangle, which suggests that they detected circles faster than triangles. This result was due mainly to the difference in the 3×3 matrices. Participants were also more accurate when responding for matrices with a circle than for matrices with a triangle in the 3×3 matrices. Although the difference was not large, this result partially supported our hypothesis. In contrast, this result did not match

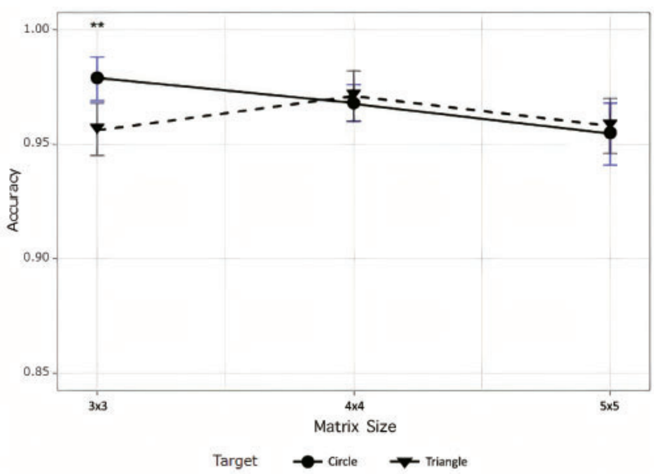

Figure 4. Experiment 1: Accuracy According to Target × Matrix Size Interaction (**$p < .01$). Error bars represent 95% CI.

Larson et al.'s (2007) findings. These authors indicated that a downward-pointing triangle, similar to the geometric configuration of an angry face, captured attention more rapidly than a circle, similar to the geometric configuration of a happy face. However, our results indicated that the circle shape captured attention slightly faster when we introduced different distractor stimuli and controlled for the balanced presentation of low-level features.

Both targets showed an increase in RT as the matrix size increased. These findings indicated that the response for these simple geometric shapes loses speed to guide attention as the number of distractor stimuli increases.

Last, participants responded faster to matrices with Tricircle Distractor than to matrices with Circangle Distractor, both with the circle target and the downward-pointing triangle target. This tendency was similar for the matrices with only distractors. The faster processing of Tricircle Distractors may be related to a directional preference in visual perception (Nachshon, 1985). Olivers et al. (2014) suggested that reading and writing direction may influence nonlinguistic tasks such as visual search ones. Nachson et al. (1999) showed that people scan visual stimuli in a direction that is consistent with the acquired reading/writing habits. If this was the case, it would be easier to process the stimuli when participants first process a half-triangle and then a half-circle (Tricircle) than first a half-circle and then a half-triangle (Circangle) in the same stimulus. However, we cannot determine whether this ease of processing was due to the initial processing of a half-triangle or the final processing of a half-circle. Moreover, this hypothesis would not be plausible if the stimulus were processed holistically.

In summary, Experiment 1 showed three main findings: (a) Participants responded to matrices with a circle and matrices with a downward-pointing triangle similarly fast in a speeded response task, except for 3×3 matrices, where they responded to the matrices with a circle significantly faster than matrices with a triangle; (b) the response slopes (i.e., the RT $\times$ Matrix Size functions) seem similar both in circles and triangles; and (c) the matrices with the Tricircle Distractor composed of a half-triangle on the left and a half-circle on the right were solved faster.

Experiment 2

Experiment 1 results did not match either our hypothesis (completely) or the findings of Larson et al. (2007). Moreover, the difference between the two distractors was unexpected, as both were composed of the same halves. Consequently, we replicated the same experiment at the University of Seville. Following Experiment 1, we expected that participants would respond slightly faster to the matrices with a circle than to matrices with a downward-pointing triangle.

Methods

Participants. The calculation for the sample size was the same as for Experiment 1. Sixty undergraduate students (12 male) from the University of Seville took part in the experiment in exchange for course credits ($M_{\text{age}} = 21.22$, $SD_{\text{age}} = 4.93$). All participants reported having normal or corrected-to-normal vision and provided written consent. The experiment received approval by the Ethics Committee of the University of Seville, and it was conducted following the Declaration of Helsinki (2008).

Materials and Procedure. We used the same speeded response task as in Experiment 1. Participants carried out the task in a room using individual computers. They received the same verbal and written instructions before the task. The distance between the participants and the computer screen was 45 cm. Computers were equipped with Intel i5 processors and 21.5-in. screens set at 1,920 × 1,080 pixels resolution and 60 Hz.

Analysis. From 60 participants, we collected 24,000 trials. Three participants were eliminated because of an error rate greater than 25%. Delayed (211) and anticipated (0) responses were excluded from the analyses. A total of 716 trials were eliminated because of incorrect responses, and 232 trials were eliminated because of extreme value statistical cleaning as in Experiment 1. A total of 21,641 trials from 57 participants remained for the analysis of RT averages.

Results

Analyses were carried out as in Experiment 1. The effects of block sequence, $F(5, 56) = 0.52$, $p = .76$, $\eta_p^2 = .054$, 90% CI [0, 0.07], and subblock sequence, $F(1, 56) = .02$, $p = .9$, $\eta_p^2 = .0001$, 90% CI [0, 0.03], on RT were nonsignificant. Hence, we conducted a three-factor repeated-measures ANOVA on RT with Target (circle and triangle), Matrix (3 × 3, 4 × 4, and 5 × 5), and Distractor (Circangle and Tricircle) as within-subject factors.

Target showed a significant main effect, $F(1, 56) = 22.14$, $p < .001$, $\eta_p^2 = .28$, 90% CI [0.12, 0.42]. As in Experiment 1, participant responses were significantly faster for the matrices with the circle ($M = 711$ ms, $SD = 107$) rather than the triangle ($M = 741.7$ ms, $SD = 116$). Matrix also showed a significant main effect, $F(2, 56) = 30.95$, $p < .001$, $\eta_p^2 = .36$, 90% CI [0.36, 0.62]. Participants responded significantly faster to the 3 × 3 matrices ($M = 690$ ms, $SD = 115$) than to the 4 × 4 matrices ($M = 720$ ms, $SD = 109$), $t(56) = -2.73$, $p = .025$, $g = -.27$, 95% CI [–56.54, –2.85], and faster than to the 5 × 5 matrices ($M = 770$ ms, $SD = 112$), $t(56) = -7.93$, $p < .001$, $g = -.7$, 95% CI [–104.5, –55]. They also responded significantly faster to the 4 × 4 matrices than to the 5 × 5 matrices, $t(56) = -5.1$, $p < .001$, $g = -.45$, 95% CI [–74, –26].

Target × Matrix interaction was significant, $F(2, 56) = 4.48$, $p = .01$, $\eta_p^2 = .07$, 90% CI [0.002, 0.2]. In the 3 × 3 matrices, participants were faster responding for the matrices with a circle ($M = 669$ ms, $SD = 106$) than for the matrices with a triangle ($M = 711$ ms, $SD = 123$), $t(56) = -4.87$, $p < .001$, $g = -.36$, 95% CI [–67.46, –16.15]. In the 4 × 4 matrices, participants were also faster detecting circles ($M = 702$ ms, $SD = 103$) than triangles ($M = 738$ ms, $SD = 114$), $t(56) = -4.18$, $p < .001$, $g = -.33$, 95% CI [–61.5, –10.2]. However, in the 5 × 5 matrices, the difference between circles ($M = 762$ ms, $SD = 112$) and triangles ($M = 777$ ms, $SD = 111$) was nonsignificant, $t(56) = -1.66$, $p = .1$, $g = -.13$, 95% CI [–39.9, 11.4] (Figure 5). As in Experiment 1, we analyzed the data from the nine central positions in the 5 × 5 matrices. The difference between the matrices with the circle as target ($M = 716$ ms, $SD = 111$) and the matrices with the triangle as target (M = 727 ms, SD = 88) was not significant, $t(53) = -1.05$, $p = .3$, $d = -.14$, 95% CI [–0.41, 0.12].

As in Experiment 1, the effect of distractor was significant, $F(1, 56) = 10.97$, $p = .002$, $\eta_p^2 = .16$, 90% CI [0.04, 0.3]. Participants responded faster to Tricircle matrices ($M = 717$ ms, $SD = 104$) than to Circangle matrices ($M = 736$ ms, $SD = 119$). However, none of the interactions related to the Distractor factor was significant, either Target × Distractor, $F(1, 56) = 3.95$, $p = .052$, $\eta_p^2 = .066$, Matrix × Distractor, $F(1, 56) = 1.3$, $p = .27$, $\eta_p^2 = .02$, or the triple interaction, $F(1, 56) = .35$, $p = .7$, $\eta_p^2 = .006$.

Three linear regression analyses were carried out to examine the slope of the function relating RT to matrix size as in Experiment 1. Results showed a positive linear relationship between RT and matrix size in the three regression analyses. With the circle as a target, we

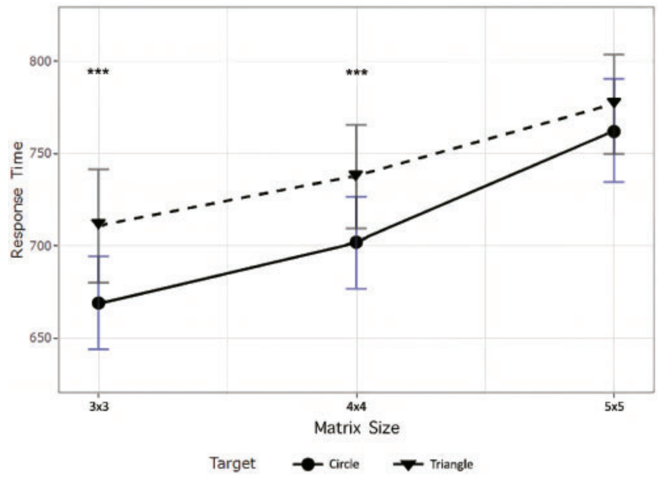

Figure 5. Experiment 2: Response Time According to Target × Matrix Size Interaction (***$p < .001$). Error bars represent 95% CI.

found a significant but weak relationship between RT and number of items, $\beta = 4.98$, $t(163) = 4.3$, $p < .001$ ($R^2_{adj} = .1$). With the triangle as a target, we also found a significant and weak relationship between RT and number of items, $\beta = 3.5$, $t(163) = 2.87$, $p = .004$ ($R^2_{adj} = .04$). Finally, with only distractors (target-absent matrices), the number of items was a strong significant predictor of slower RTs, $\beta = 14.96$, $t(170) = 7.1$, $p < .001$ ($R^2_{adj} = .22$).

We also conducted a three-factor repeated-measures ANOVA on accuracy as in Experiment 1. Results showed that, although participants were less accurate with the matrices with a triangle ($M = 0.953$, $SD = 0.055$) than with the matrices with a circle ($M = 0.961$, $SD = 0.054$), Target was not significant, $F(1, 51) = 2.56$, $p = .1$, $\eta_p^2 = .05$, 90% CI [0, 0.17]. In contrast, Matrix showed a significant main effect, $F(2, 51) = 6.37$, $p = .002$, $\eta_p^2 = .1$, 90% CI [0.04, 0.33]. Participants were less accurate in the 5 × 5 matrices ($M = 0.948$, $SD = 0.05$) than in the 3 × 3 ones ($M = 0.965$, $SD = 0.02$), $t(51) = 3.54$, $p = .002$, $g = -.44$, 95% CI [0.005, 0.03]. There were no significant differences either between 5 × 5 matrices and 4 × 4 matrices ($M = 0.957$, $SD = 0.05$), $t(51) = 2$, $p = .15$, $g = .18$, 95% CI [–0.002, 0.021], or between 4 × 4 matrices and 3 × 3 matrices, $t(51) = 1.6$, $p = .36$, $g = .21$, 95% CI [0.004, 0.020]. In this case, the Target × Matrix interaction was nonsignificant, $F(2, 51) = 0.54$, $p = .58$, $\eta_p^2 = .01$, 90% CI [0, 0.09] (Figure 6).

Discussion

Experiment 2 replicated the main findings of Experiment 1. First, participants detected the matrices with a circle faster than the matrices with a downward-pointing triangle. We found significant differences between the two targets in the 3 × 3 and 4 × 4 matrices. Overall, participants were also more accurate responding to the matrices with a circle than the matrices with a downward-pointing triangle, but the difference was nonsignificant. These results suggest that the circle had the advantage to capture attention faster than the downward-pointing triangle when we controlled for the balanced presentation of the low-level features. Second, both targets lost speed as the number of distractors increased. This suggests that the interference from distractors led participants to greater distraction, or involved a serial search for the target across the elements of the matrices. Third, as in Experiment 1, participants responded faster to matrices with Tricircle Distractor than to

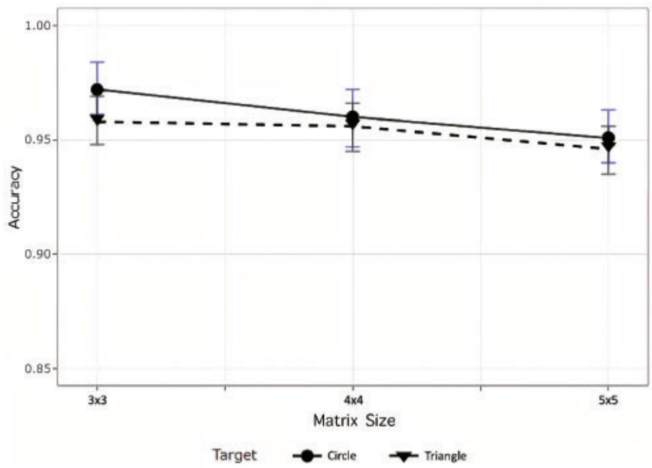

Figure 6. Experiment 2: Accuracy According to Target × Matrix Size Interaction.
Error bars represent 95% CI.

matrices with Circangle Distractor. This advantage occurred in matrices with and without targets.

General Discussion

We examined whether a downward-pointing triangle or a circle had the advantage to capture attention faster in a speeded response task. Participants had to detect whether a matrix contained all the same distractor shapes or whether there was a target stimulus. We used the circle and the downward-pointing triangle as target stimuli and combined them to create two new distractor stimuli. This was aimed to control for target stimuli similarity and the balanced presentation of low-level features. We arranged these four stimuli in 3×3, 4×4, and 5×5 matrices to create the speeded response task. We used the task in two experiments. Experiment 1 was carried out at the University of the Balearic Islands, and Experiment 2 was carried out at the University of Seville. The objective of Experiment 2 was to replicate the unexpected results of Experiment 1.

In both experiments, participants responded faster to the matrices with a circle than the matrices with a downward-pointing triangle. However, there was a special pattern of results as a function of the matrix size. Responding to a circle was significantly faster than responding to a downward-pointing triangle with the 3×3 matrices in both experiments. With the 4×4 matrices, the difference only was significant in Experiment 2. With the 5×5 matrices, there was no difference. Similarly, although participants were highly accurate in both experiments, the differences revealed an overall better performance with the circle as target than with the downward-pointing triangle as target, especially in the 3×3 matrices of Experiment 1. This pattern shows that the difference between circles and triangles is significant in small matrices, but it decreases and becomes nonsignificant in large matrices with mixed results in the medium matrices. Consequently, we analyzed the RT in the nine central positions of the 5×5 matrices, that is, the nine positions that were the same as in the 3×3 matrices. Although participants also showed faster responses for circles than for triangles in both experiments, these differences were nonsignificant. This result showed that the faster RT for circles in the 3×3 matrices comes from the number of items and not from their position. It may be related to the crowding phenomenon (Whitney & Levi, 2011).

The slope of the RT by matrix size functions represents the mean time consumption of each additional item in the target-present and target-absent matrices. In the target-present matrices, the functions with downward-pointing triangles as target showed slopes lower than 4.0, whereas the functions with circles as target showed slopes around 5.0. However, the slope difference between the two targets seems to be due to the higher initial value of the triangle function in the 3×3 matrices. Furthermore, the adjustment of the data to the triangle function is weaker than to the circle function.

Our findings partially support that curved shapes enhance visual response over straight and sharp-angled shapes (Bertamini et al., 2019; LoBue, 2014; Lobue & Deloache, 2010; Treisman & Gormican, 1988; Wolfe et al., 1992). Other studies indicated that downward-pointing triangles evoked more rapid responses than circles because of a threat perception advantage (Larson et al., 2007, 2009). However, they used a noncontrolled target-distractor similarity, and three stimuli indistinctly as targets and distractors: circles, downward-pointing triangles, and upward-pointing triangles. It was not possible to know whether the advantage to detect downward-pointing triangles emerged from a true advantage of a shape or from the fast processing of the other shapes as distractors. Larson et al. (2007) based their conclusions in a slight difference in Experiment 3. Moreover, in three of their experiments, matrices with only circles had lower RTs than matrices with only upward-pointing triangles and matrices with only downward-pointing triangles. They also used a grid to insert the shapes. The triangles and the angles in the grid could have influenced the performance differently across conditions.

Hansen and Hansen (1988) suggested that threatening faces pop out of crowds and lead to a parallel visual search. However, this result was due to low-level visual confounds (Purcell et al., 1996; Savage et al., 2016), and facial expressions do not pop out of crowds (Cave & Batty, 2006; Fox et al., 2000; Nothdurft, 1993). With simple geometric shapes that could evoke anger (triangles) and pleasantness (circles), we found no advantage for responding to downward-pointing triangles. On the contrary, our findings showed a tendency for faster response to the circles which disappeared as matrix size increases. One of the possible explanations of this result is that the faster response to the circles appears only in small sets because the situation is more comfortable, but it disappears when the situation is crowded, as if comfort also disappears.

Low-level stimulus features can lead to differences in search efficiency (Savage et al., 2013). Several studies found an increased sensitivity to detect curved features in visual search displays (Andrews et al., 1973; Treisman & Gormican, 1988; Wilson et al., 1997; Wolfe et al., 1992). Pasupathy showed that the explicit representation of curvature in area V4 might provide a physiological basis for increased sensitivity to curvature (Pasupathy, 2006; Pasupathy & Connor, 1999, 2001, 2002). Other studies suggested a perceptual bias for the detection of simple curvilinear shapes because they are "snake-like" stimuli (Isbell, 2006, 2009; LoBue, 2014; Lobue & Rakison, 2013). However, Van Strien et al. (2016) suggested that the superior threat detection of "snake-like" stimuli was not only driven by the curvature of snakes, but most probably also by other threat-relevant physical and contextual cues. Subra et al. (2018) supported the *snake-like* hypothesis, but they found that modern threats captured attention faster than ancient threats. They suggested a relevance-based explanation rather than an evolutionary-based explanation of threat detection. Interestingly, Coelho et al. (2019) reported several challenges to evolutionary-based explanations of the snake detection theory and highlighted that the low-level features of the visual stimulus could have affected previous findings. Wolfe (2018) also suggested threat perception as a probable nonguiding attribute in visual search when the other basic features are controlled for. Instead, curvature was proposed as a probable guiding aspect of low-level shape features that leads to an efficient visual search (Sakai et al., 2007; Treisman & Gormican, 1988; Wolfe, 2018; Wolfe et al., 1992). That is, curvature might elicit similar RTs independently of the number of items in a matrix. Some of these studies highlight the role of low-level features in visual processing. We used simple geometric shapes and introduced distractor stimuli to control for the balanced presentation of low-level features and target stimulus similarity in a speeded response task. Although our findings are constrained to geometric shapes related to emotional expressions, the use of our neutral stimuli could contribute to understanding the role of low-level features in attentional and perceptual experience.

From the viewpoint of the anger versus happiness superiority effects, our results support the latter. Previous studies reported a relationship between curvilinearity and faces. Yue et al. (2014) presented curved versus sharp-angled natural stimuli (e.g., faces and objects) and computer-generated shapes (e.g., spheres and pyramids) to macaque monkeys in a functional magnetic resonance imaging scanner. They found three cortical patches hierarchically organized processing simple curvature, moderately complex curved features, and shapes mainly composed of curved features, respectively. Interestingly, this curvature-processing network was adjacent to a well-known face-processing network. Therefore, they suggested a possible functional link between curvature and face processing. Moreover, people associate curved features with positive valence and sharp-angled features with negative valence. Palumbo et al. (2015) pointed out the role of affective processes underlying preference for curvature. They reported that the implicit association between positive valence and curvature was stronger than the association between negative valence and sharp-angled features. We prefer curved shapes over sharp-angled ones (Corradi & Munar, 2020; Corradi et al., 2018; Gómez-Puerto et al., 2016). Altogether, the affective association between curvature and positive valence could be interpreted from the happiness superiority effect, which may explain that the circle evokes rapid capture of attention.

However, we believe that known geometric shapes are not the best stimuli to test this hypothesis. Some geometric shapes are associated not only with an affective value (Watson et al., 2011, 2012) but also with semantic meaning. Such semantic meaning could impact preference for shapes (Leder et al., 2011). Moreover, an efficient visual search or speeded response requires the target to be sufficiently different from the distractor stimulus (Duncan & Humphreys, 1989). This raises the possibility that our distractor stimuli were too similar to the targets. Thus, we need to test more basic stimuli and to introduce different distractor stimuli to investigate the role of low-level visual features guiding attention.

A related limitation is that our distractors were homogeneous within each matrix (Becker et al., 2011). However, we wanted to minimize the impact of low-level features so we combined both target shapes in the distractors to control for target stimuli similarity (Savage et al., 2016). We also tried to control distractor stimulus directionality; hence, we created the two distractor versions. We used them separately within each subblock to hold distractors and participants' expectations constant across conditions. Nevertheless, we found faster processing with Tricircle Distractor than with Circangle Distractor. A possible explanation of this finding is the influence of reading and writing directional preference role in visual perception (Nachshon, 1985). Olivers et al. (2014) showed that literacy affects the way people sample the visual world and when they are seeking target objects from competing information. Thus, they suggested that reading and writing direction might also influence other visual tasks. People scan visual stimuli in the same direction that they acquired reading/writing habits (Nachson et al., 1999). We could expect that our participants visually processed distractor stimuli from left to right. When the half-triangle was on the left (Tricircle), it may have led to faster discrimination of the circle target, whereas it may have led to slower discrimination of the triangle. On the other hand, when the half-circle was on the left (Circangle), it may have led to more difficult discrimination of the circle target, but it may also have led to even more difficult discrimination of the triangle target because the half-circle could have captured participants' attention. Consequently, the influence of the faster processing of Tricircle was similar in both target stimuli.

In summary, we used a speeded response task in two experiments, finding that the circles captured attention faster than the downward-pointing triangles. However, this circle's superiority to capture attention disappears as the number of distractors increases. We suggest that circles may capture attention faster because of the low-level feature of curvature (Wolfe, 2018). However, circles and triangles are associated with semantic meaning and affective values. Therefore, they may not be the most suitable stimuli to test the natural propensity of their features to guide attention. We also highlight the need to balance the presentation of low-level features to explore visual attentional processing. Then, we could conclude that a given stimulus could drive attentional and perceptual experience.

Data Accessibility Statement

The data sets generated and analyzed during the current study is available on the Open Science Framework: https://osf.io/cbqkr/

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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ORCID iD

Erick G. Chuquichambi https://orcid.org/0000-0001-5389-283X

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3.3. When symmetric and curved visual contour meet intentional instructions

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When symmetric and curved visual contour meet intentional instructions: Hedonic value and preference

Erick G Chuquichambi[1], Guido B Corradi[2], Enric Munar[1] and Jaume Rosselló-Mir[1]

Abstract

Symmetry and contour take part in shaping visual preference. However, less is known about their combined contribution to preference. We examined the hedonic tone and preference triggered by the interaction of symmetry and contour. Symmetric/curved, symmetric/sharp-angled, asymmetric/curved, and asymmetric/sharp-angled stimuli were presented in an implicit and explicit task. The implicit task consisted of an affective stimulus–response compatibility task where participants matched the stimuli with positive and negative valence response cues. The explicit task recorded liking ratings from the same stimuli. We used instructed mindset to induce participants to focus on symmetry or contour in different parts of the experimental session. We found an implicit compatibility of symmetry and curvature with positive hedonic tone. Explicit results showed preference for symmetry and curvature. In both tasks, symmetry and curvature showed a cumulative interaction, with a larger contribution of symmetry to the overall effect. While symmetric and asymmetric stimuli contributed to the implicit positive valence of symmetry, the effect of curvature was mainly caused by inclination towards curved contours rather than rejection of sharp-angled contours. We did not find any correlation between implicit and explicit measures, suggesting that they may involve different cognitive processing.

Keywords

Symmetry; curvature; mindset; implicit; hedonic value; visual preference

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Low-level visual features shape aesthetic visual preference, with a common set of features shared across cultures (Che et al., 2018). Research on basic visual features that predict aesthetic preference is quite dispersed, variably focusing on balance (Hübner & Fillinger, 2016; Wilson & Chatterjee, 2005), brightness (Graham et al., 2016), complexity (Güçlütürk et al., 2016; Nadal et al., 2010), contour (Gómez-Puerto et al., 2017; Munar et al., 2015), contrast (van Dongen & Zijlmans, 2017), proportion (Pittard et al., 2007), self-similarity (Street et al., 2016; Viengkham & Spehar, 2018), and symmetry (Bertamini et al., 2013; Jacobsen & Höfel, 2003; Pecchinenda et al., 2014), among others. While most studies consider these features in isolation, less is known about how interactions of features affect hedonic valuation and preference. As Makin (2017) stated, stimulus-preference law is likely to be twisted or modulated when another feature is also evaluated, explicitly or not. By contrast, the specification to contrast the nomothetic versus the ideographic approach on aesthetic research (i.e., judgements at a group level vs. judgements at an individual level) seems to attain special relevance (Jacobsen & Höfel, 2002). Consequently, more studies are needed in order to understand how these interacting features contribute to general and particular preference.

Early studies discussed the interaction between visual features to define formal measures of aesthetic preference (Birkhoff, 1932; Eysenck, 1941, 1968). These measures

[1]Human Evolution and Cognition Group (EvoCog), Faculty of Psychology, University of the Balearic Islands, Palma de Mallorca, Spain
[2]Department of Psychology, Faculty of Education and Health, University Camilo José Cela, Madrid, Spain

Corresponding author:
Erick G Chuquichambi, Human Evolution and Cognition Group (EvoCog), Faculty of Psychology, University of the Balearic Islands, Campus. Ctra. de Valldemossa km 7.5, 07122 Palma de Mallorca, Balearic Islands, Spain.
Email: erik.chuquichambi@uib.es

predict diverse relationships between features and preference. In the past decades, several studies further examined human preference for such interactions. Eisenman (1967), for instance, found preference for symmetry and simplicity, and suggested a rejection of complexity for asymmetrical shapes. In a following study, Eisenman and Gellens (1968) showed that complex shapes are preferred only in conjunction to symmetry, suggesting that symmetry tends to simplify complexity. In turn, Jacobsen and Höfel (2002) reported that symmetry, followed by complexity, shows the highest correlations with beauty. Likewise, Tinio and Leder (2009) found that symmetry is a stronger predictor of beauty than complexity, suggesting that the influence of complexity on aesthetic judgement is sensitive to massive familiarisation, while the influence of symmetry is not.

Complexity also was studied in conjunction to kind of contour. Silvia and Barona (2009) found that non-expert participants prefer curved rather than angular polygons both for simple and complex shapes. In turn, complex over simple polygons are preferred, both for curved and angular contours. However, these interactions changed depending on artistic expertise. Using node-link diagrams, Carbon et al. (2018) found that beauty is mostly based on curvature aspects at short presentation times, while complexity is considered when time is unrestricted, although the effect is in the opposite direction: the more complex the stimulus, the less liked.

Other studies used multidimensional stimuli to test the relationships between stimulus features and preference. Makin (2017) found preference for symmetrical over random arrangements, and blue over brown, although no difference was found between circles and squares. However, squares rather than circles were preferred for random arrangements. The interaction between sessions showed that preference for symmetry and preference for blue were significantly higher in the simple than in the combined session. Mayer and Landwehr (2018) suggested that the most determinants of aesthetic liking for abstract artworks are, in descending order, self-similarity, contrast, symmetry and complexity. However, the results of Studies 2 and 3 in their work did not support these results, especially in relation to expertise and landscape images. Furthermore, the authors did not report the interactions between the four features, incorrectly assuming that all four measures contributed independently to aesthetic liking. According to Makin (2017), is unrealistic to assume that all the features from a specific stimulus are orthogonal and that their effects on preference are independent.

Furthermore, the effects of feature interactions on evaluations do not depend only on the stimulus characteristics. As has been widely proven at the detriment of the naive realism prospect (Ross & Ward, 1996), a variety of goal-driven and framing factors influence the evaluation of perceptual features (Skov & Nadal, 2019). Prior knowledge, expertise, context, cognitive demands, mental sets, and instructions, among others, are variables whose effects need to be considered to better understand human preference. The manipulation of these factors, namely instructed mindsets and if-then rules (task-sets, from now on), are helpful to examine features evaluation, while facilitating performance and improving measurement quality as discussed below.

People use different strategies to better perform tasks. Both mindsets and task-sets are relevant in improving the readiness for a task, the persistence in its execution and the filtering of incidental (i.e., irrelevant) information (Fujita et al., 2007). Mindsets, understood as instructed proactive dispositions to focus on specific features to arrange task-sets, favour the narrowing of attention on task-relevant information and the tuning towards goal implementation (Armor & Taylor, 2003; Gollwitzer, 2012; Gollwitzer & Bayer, 1999). These mindsets (implemental mindsets by Gollwitzer & Bayer, 1999) enhance the correspondence between attitudes and behaviour (Henderson et al., 2008). Interestingly, as mindsets imply different ways to process information (Gollwitzer, 2012), they are likely to influence our evaluations. Indeed, implemental mindsets seem to reduce the evaluative ambivalence towards unrelated attitude objects (Henderson et al., 2008). Like mindsets, task-sets, meant as stimulus-response mappings guiding execution, can be effectively implemented by instructions (Meiran et al., 2015). Recent findings reveal that novel instructions can immediately lead to an efficient and autonomous execution (Liefooghe & Verbruggen, 2019). This proactive effect of the instructed task-sets has been interpreted as a form of automaticity without practice (Meiran et al., 2017).

The "power" of instructions have been studied especially on Stimulus Response Compatibility (SRC) effects (e.g., Cohen-Kdoshay & Meiran, 2007). In the case of affective SRC (aSRC), hedonic similarity between feature and response lead to SRC (Fitts & Deininger, 1954), while affective disparity leads to incompatibility. Instructed task-sets define compatibility-incompatibility mappings on the basis of the assumed valence of features and responses. This way, a better performance is expected when the valence of the feature and the valence of the response match, compared with when they mismatch (De Houwer & Eelen, 1998). This effect can occur even when the affective valence of the feature is irrelevant for the task (De Houwer, 1998). Strikingly, when the instructed task-sets define the hedonic value of the response (e.g., to select a happy face when the stimulus is curved) the affective meaning attached to the response depends on this intention-based coding rather than on stimulus-response associations (Eder & Rothermund, 2008). In other words, the cognitive representation of responses determines the attached valence and, therefore, the compatibility effects. If the compatibility conditions are constructed at the cognitive level (i.e., without the need of previous associations) it is possible to dispense with the block structure and the task-switching cost of the standard IAT (Implicit Association Test) (Greenwald et al., 1998). This way, the reliability and the validity of the measurement procedure tend to improve. This seems to be the case for the aSRC task used by Eder et al. (2013), on which our task is inspired. This variant of the IAT partially circumvent some of its major shortcomings, namely response recoding, category re-definition, task-switching drawbacks and sensibility to stimulus selection (Teige-Mocigemba et al., 2010).

In visual aesthetics, the experimental procedures have scarcely explored the role of instructions, with a few exceptions. Höfel and Jacobsen (2007a, 2007b) manipulated instructions to compare spontaneous and intentional processing of symmetric and asymmetric patterns. In contrast, a wide number of studies applied aSRC tasks (commonly referred to as implicit measures), often in combination with explicit counterparts. Most of these works used the IAT (Greenwald et al., 1998) to explore presumed implicit preference both for symmetry (Bertamini et al., 2013; Makin et al., 2012; Weichselbaum et al., 2018) or curvature (Palumbo et al., 2015), and for artistic or decorative paintings (Pavlović & Marković, 2012), architectural styles (Mastandrea et al., 2011), design objects (Mastandrea & Maricchiolo, 2014), and wallpaper patterns (Fu et al., 2019). Despite its valuable contribution to test hedonic tones attached to visual features, most studies share an unfortunate misunderstanding. To different degrees, they assume that the standard valence-IAT directly measures implicit or automatic preference. Instead, the valence-IAT, insofar as it is an aSRC task, indirectly measures the hedonic valuation from which preference and, more generally, aesthetic evaluation might stem (Becker et al., 2019). In fact, although Weichselbaum et al. (2018) interpreted IAT outcomes as "implicit preferences," they expressly warned in advance: "Note that the IAT effect does not directly reveal implicit preferences but show how strongly two concepts are related" (Weichselbaum et al., 2018, p. 3). Likewise, Pavlović and Marković (2012) argued that the IAT effects reveal basic hedonic reactions on which, at least partially, the aesthetic assessments are based on. Overall, the evidence suggests that, although different evaluative judgements stem from a common hedonic value, they additionally engage different cognitive processes to different extent (Huang et al., 2020; Leder & Nadal, 2014; Miller & Hübner, 2020).

The present study

The current study aims to contribute to further understanding of hedonic responses and preference triggered by the interaction of visual symmetry and contour. Specifically, we use four types of patterns that combine two categories of symmetry (symmetric vs. asymmetric) and two categories of contour (curved vs. sharp-angled). On the one hand, the procedure is aimed to indirectly measure, with an aSRC task, the hedonic response triggered by the combined categories (i.e., curved-symmetric, curved-asymmetric, sharp-symmetric, sharp-asymmetric). On the other hand, it is planned to directly evaluate the explicit preference of the stimuli. We use intention-based instructions to sequentially induce two mindsets (e.g., symmetry and contour). Both the indirect and the explicit tasks have two parts. Participants are induced to focus in a feature (the relevant feature) in each part. For the aSRC task, we define two mutually complementary task-sets for each mindset in order to map the compatible and incompatible conditions (see the "Procedure" section). In this regard, it is crucial to keep in mind that these conditions were defined according to the hypothesised assumption that, when relevant for response selection, the symmetric category and the curved category would give rise to positive hedonic values, while negative valences would be coupled with asymmetric and sharp-angled features. Note that the stimuli used are bivalent, that is, they exhibit both symmetry and contour features. This bivalency, together with the instructed mindsets and task-sets, allows us to study participants' assessments using the same set of stimuli and constant response sets.

Together, the procedure outlined above aim to broaden our knowledge in four respects:

1. Since the hedonic values of symmetry and curvature are assumptions, the instructed task-sets should serve to test the predicted affective meaning for each of the four combined categories. If the compatibility/incompatibility mappings were confirmed, this would suggest that the expected hedonic values correspond to their actual values. On the contrary, the results will contribute to understand how the hedonic value for each category of the relevant feature changes according to the category of the irrelevant feature.
2. Given that the hypothesised valences of the stimulus categories are irrelevant for the task at hand, the evidence of compatibility/incompatibility effects would suggest a high degree of automatism, both in processing and response implementation, of this hedonic value.
3. Mindsets could differently affect hedonic valuation and preference for symmetry and curvature. Given the fact that previous research has shown the modulating influence of memory load and response temporal constrains on the effects of implemental mindsets (Gollwitzer, 2012; Meiran et al., 2012), we examine the interaction between mindsets and type of task (aSRC vs. explicit task).
4. Finally, we intend to ascertain whether the combination of categories and mindsets affect evaluations in an additive way both for the indirect and the explicit tasks, that is, both for hedonic value and preference.

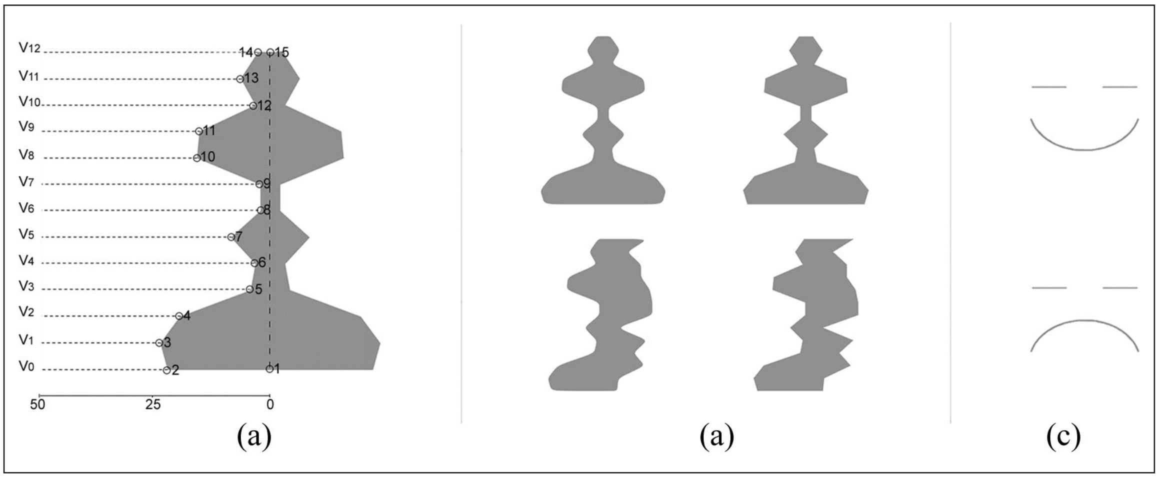

Figure 1. (a) Pattern of 15 points used to design the stimuli. (b) The four types of abstract patterns. (c) Schematic facial expressions used as response cues: happy and sad.

Method

Participants

In all, 65 volunteer undergraduate students (12 male) from the University of the Balearic Islands (UIB) (age: $M=21.55$, $SD=3.98$) took part in the experiment in exchange for credits in the course. All participants reported normal or corrected-to-normal vision and provided written consent before the experiment. The experiment received approval by the Research Ethics Committee (CER) of the UIB and was conducted in accordance with the Declaration of Helsinki (2008).

Materials

We created 48 abstract grey patterns to minimise characteristics related to visual preferences such as semantic content, familiarity and affective valence (Leder et al., 2011). The images were designed with EazyDraw (Version 7; Dekorra Optics LLC, Poynnette, WI, USA). These images were sets of 4 stimuli based on patterns of points (Figure 1a and b). To obtain the symmetric sharp version of the stimulus 15 points were vertically distributed in 13 levels spaced equally apart. The first and the second points were at the same vertical level (V0), and the 14th and the 15th at the last level (V12). The horizontal axis values were randomised from 0 to 50, except for the first and last points, which remained at 0. Subsequently, all 15 points were joined by segments, constituting half of the contour, which was duplicated and flipped onto the vertical axis. For the asymmetric sharp version, a new 13-point pattern was created following the aforementioned procedure, and then merged with the first pattern. When creating the asymmetric version, we controlled that the number of concavities and convexities were the same on both sides and occupied the same area as the symmetric version. When the number of concavities and convexities did not match, new values were randomly selected for the second pattern until the image had the appropriate number of concavities and convexities. Finally, to create the curved versions, we used the tool Transform Round in EazyDraw to transform a sharp-angled contour into a curved contour using a constant parameter. In each stimulus set, we equalised the area slightly enlarging or diminishing the stimulus. Image sizes were set at 321×463 pixels. In all, we obtained 12 stimuli for each combination of categories: symmetric-curved, symmetric-sharp, asymmetric-curved and asymmetric-sharp (Figure 1b).

Since some studies suggest that when responses acquire evaluative meaning SRC tasks achieve some of the benefits of single-categorisation paradigm (Eder et al., 2015; Govan & Williams, 2004), we framed responses using happy and sad schematic expressions as response keys (Figure 1c). The expressions consisted of two simple straight lines representing eyes, and a half-ellipse, which was turned down, representing a sad mouth, or turned up, representing a happy mouth. We minimised the effect of curvature and symmetry of the eyes sketching them as simple lines. Images were resized at 120×200 pixels. These response keys were designed considering Salgado-Montejo et al. (2017)'s conclusions, according to which these simple lines represent specific affective states (happy and sad).

Participants carried out the experimental task using individual computers in isolated cabins with similar light conditions and with an approximate distance to the screen of 45 cm. The task was designed with OpenSesame (3.1) software (Mathôt et al., 2012). Computers were equipped with Intel i5 processors and 21-in. screens set at $1,920 \times 1,080$ pixels resolution and 60 Hz. The stimuli

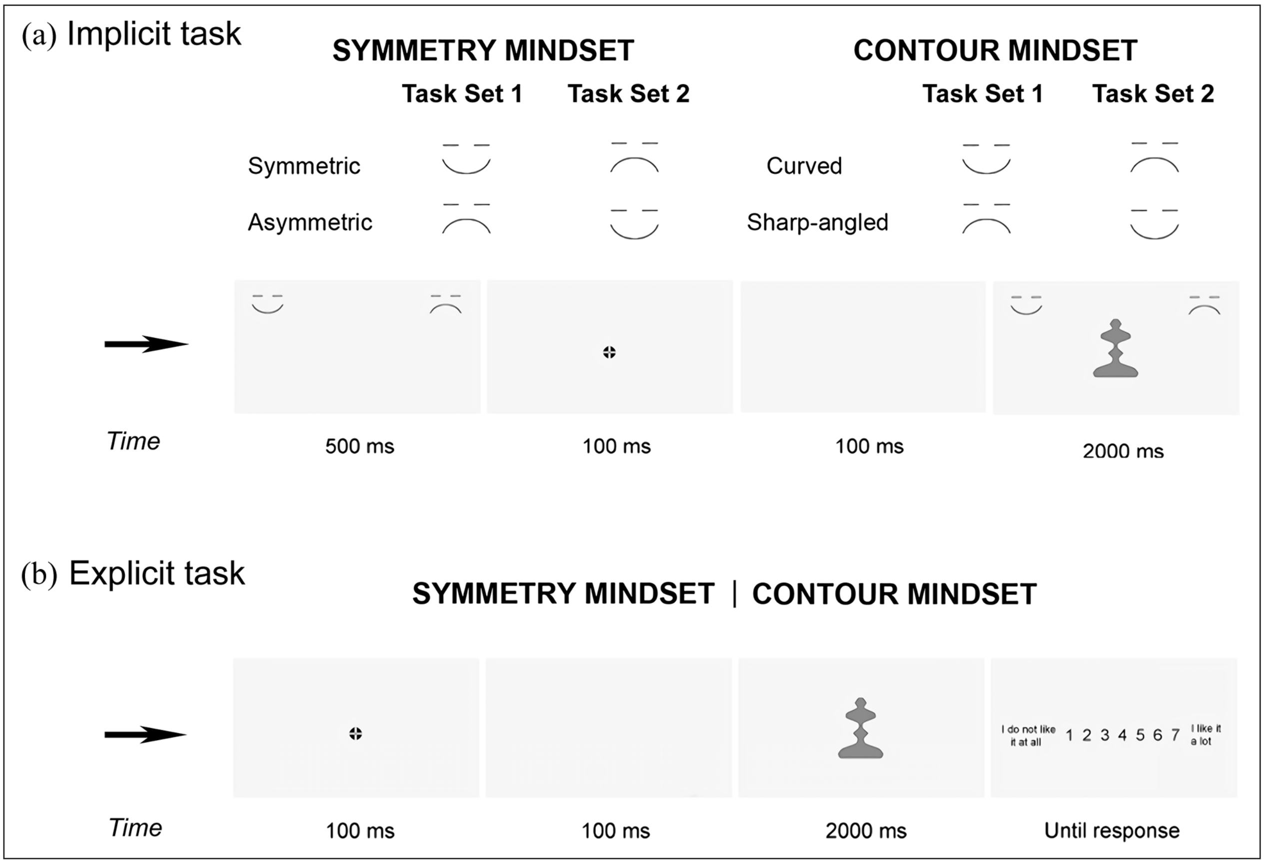

Figure 2. (a) Implicit task. An affective SRC task with two mindsets presented in two different parts: Symmetry and Contour. Each mindset had a Task-set 1 and a Task-set 2. In the Symmetry mindset, instructions were based on whether the stimulus was symmetric or asymmetric. In the Contour mindset, instructions were based on whether the stimulus was curved or sharp-angled. (b) Explicit task. A liking rating task with the same mindsets as the implicit task.

measured 14.37 cm on the vertical axis and 10 cm on the horizontal axis.

Procedure

For the indirect assessment of the hedonic value we designed a revised version of the aSRC task proposed by Eder et al. (2013). This variant, although closely related to the standard IAT, partly avoids some of its limitations, as explained in the introduction. Hence, we removed the classical block structure and dispensed with the label trials in order to reduce the method-specific variance (Mierke & Klauer, 2003).

The aSRC task consisted of two main parts, one for each type of mindset. Intention-based instructions were used to activate either a symmetry mindset or a contour mindset, thus making participants to selectively attend to only one of the features. For each mindset, both an assumed compatibility block and an assumed incompatibility block were defined by means of the instructed task-set. Thus, each part of the administration consisted of one block for the expected compatible Task-set (Task-set 1, from now on) and another block for the expected incompatible one (Task-set 2, from now on) (see Figure 2a).

Participants received verbal instructions before the whole experimental session and written instructions before each part and before each task-set. Regarding the contour part, they were instructed that curved or sharp-angled shapes would be presented. In the Task-set 1 their task was to match the curved stimuli with the happy expression and the sharp-angled stimuli with the sad one, whereas in the Task-set 2 they had to match the curved stimuli with the sad expression and the sharp-angled stimuli with the happy one. As for the symmetry part, they were instructed that symmetric or asymmetric shapes would be presented. In the Task-set 1, they had to match the symmetric stimuli with the happy expression and the asymmetric stimuli with the sad one, whereas in the Task-set 2 they had to match the symmetric stimuli with the sad expression and the asymmetric stimuli with the happy one. In each part and task-set, participants were required to carry out the discrimination task as fast as possible.

To prevent mechanical classification, the response keys—sad and happy schematic facial expressions—appeared randomly on either side—right or left—across trials and across participants, as in other Implicit Association Tasks (e.g., De Houwer et al., 2005; Rothermund et al., 2009). Participants responded by pressing "z" (for the left face) or "m" (for the right face). They received feedback about incorrect and delayed trials. There were 12 practice trials before each Task-set. Part sequence was counterbalanced. Specifically, 33 participants carried out the symmetry part first and 32 participants carried out the contour part first. In every part, all participants first carried out the Task-set 1 and just after the Task-set 2. This fixed sequence was based on previous studies and a broad meta-analysis (Hofmann et al., 2005) that indicated that counterbalancing compatibility might artificially increase implicit-explicit correlations compared with a fixed sequence of compatibility and incompatibility blocks. Trials presentation was randomised. Completing the experiment took about 15 min.

After the aSRC task, participants carried out the explicit task with the same stimuli. According to the meta-analysis by Hofmann et al. (2005), the order of implicit and explicit measurement does not affect implicit-explicit correlations. In the explicit task, participants had to rate with a Likert-type scale from 1 (*I don't like it at all*) to 7 (*I like it a lot*) how much they liked each stimulus based on a contour mindset in one part and based on a symmetry mindset in the other (Figure 2b). As in the case of the aSRC task, this mindset manipulation was induced by asking participants to base their ratings in the correspondent feature (contour or symmetry). There were 2 practice and 48 experimental trials in each part. The sequence of parts was counterbalanced, and trials presentation was randomised.

Analysis

In the aSRC task, we collected 12,480 experimental trials and discarded the practice ones. As only correct responses were considered, 1,189 incorrect trials were excluded from the analysis (9.53% of total trials). We identified two participants with error rates above 30%, who were dropped from the analysis (237 trials). Delayed (above 2,000 ms) and anticipated (300 ms) responses were excluded from the whole trial sample (204 trials, 1.85%). After data cleaning, 10,850 trials from 63 participants remained.

Results

Analyses were conducted with SPSS 22.0.0 (SPSS Inc., Chicago, IL, USA) or R environment for statistical computing (R Core Team, 2018), using an alpha level of .05. Post hoc tests used Bonferroni correction. We calculated confidence intervals (CIs) for effect sizes using an ad hoc script (http://daniellakens.blogspot.com.es/2014/06/calculating-confidence-intervals-for.html), ascertaining the obtained values with the "MBESS" package from the R statistical software (Kelley, 2007).

ASRC task

Following Eder et al. (2013), the analyses focused on participants' mean response time (RTs)—instead of on a *D* score, as used to be the case for this kind of implicit tasks (Greenwald et al., 2003). This way, we examined the interactions between Task-set 1 and 2, and Mindset, Contour, and Symmetry variables.

The sequence of parts was not significant, $F(1, 62) = .323$, $p = .572$, $\eta_p^2 = .005$, 90% CI = [0, 0.009]. Thus, we conducted a four-factor mixed ANOVA on RT with Mindset (Contour vs. Symmetry), Task-set (1 vs. 2), Contour (Curved vs. Sharp-angled) and Symmetry (Symmetric vs. Asymmetric) as within-subject factors. All the results from the ANOVA are in Table 1.

Results yielded a significant main effect of Task-set. Participants performed faster in Task-set 1 ($M = 965$, $SD = 144$) than in Task-set 2 ($M = 1{,}064$, $SD = 180$). Participants were faster either when pressing the happy-key to respond to curved or symmetric stimuli or the sad-key to respond to sharp-angled or asymmetric stimuli than when they responded either by pressing the happy-key to sharp-angled or asymmetric stimuli or the sad-key to curved or symmetric stimuli. This result supported Task-set 1 as the compatible condition between stimulus and response, and Task-set 2 as the incompatible condition. Therefore, from now on, we consider Task-set 1 as the compatible condition and Task-set 2 as the incompatible condition. All other main effects were nonsignificant.

Results showed four significant two-way interactions. Two of them involved affective Compatibility, which was directly related to the objective of the research. The other two significant interactions, Contour × Symmetry and Mindset × Symmetry, were related to processing time of specific kinds of stimuli.

The significant interaction Mindset × Compatibility (Figure 3) shows that, although the effect of Compatibility was significant both in symmetry and contour mindsets, the effect size was higher in symmetry, $t(62) = 7.522$; $p < .001$; $g = .726$; 90% CI = [0.54, 0.926], than in contour, $t(62) = 3.265$; $p = .002$; $g = .351$; 90% CI = [0.168, 0.541]. As the CIs of the effect sizes do not overlap, we conclude that the symmetry mindset influenced the affective Compatibility measure more than the contour mindset. That is, symmetry made a larger contribution than curvature to the hedonic valuation.

Compatibility × Contour was also significant. Regarding our objectives, the interesting point of this interaction is that the difference between compatible and incompatible trials was higher with curved stimuli, $t(62) = 7.029$, $p < .001$, $g = .677$, 90% CI = [0.505, 0.892], than with sharp-angled stimuli, $t(62) = 5.163$, $p < .001$, $g = .459$, 90% CI = [0.312, 0.652]. As the two CIs slightly overlap, we cannot sustain that the affective compatibility effects are different in curved and sharp-angled stimuli.

Table 1. Implicit task analysis.

Factor	F	p	η_p^2	90% CI
Mindset	0.087	.77	.001	[0, 0.05]
Task-set (Compatibility)	43.9	<.001***	.415	[0.26, 0.53]
Symmetry	3.37	.07	.052	[0, 0.16]
Contour	0.30	.59	.005	[0, 0.07]
Mindset × Compatibility	10.17	.002**	.14	[0.03, 0.27]
Mindset × Symmetry	4.64	.035*	.06	[0, 0.21]
Mindset × Contour	2.56	.11	.04	[0, 0.14]
Compatibility × Symmetry	0.22	.64	.003	[0, 0.06]
Compatibility × Contour	8.2	.006**	.117	[0.02, 0.24]
Symmetry × Contour	17.66	<.001***	.22	[0.08, 0.36]
Mindset × Compatibility × Symmetry	0.11	.74	.002	[0, 0.05]
Mindset × Compatibility × Contour	3.43	.07	.05	[0, 0.16]
Mindset × Symmetry × Contour	1.05	.31	.017	[0, 0.1]
Compatibility × Symmetry × Contour	0.25	.62	.004	[0, 0.064]
Mindset × Compatibility × Symmetry × Contour	0.21	.65	.003	[0, 0.061]

CI: confidence interval.
[2](Mindset: Contour vs. Symmetry) × 2 (Task-set 1 vs. Task-set 2) × 2 (Contour: Curved vs. Sharp-angled) × 2 (Symmetry: Symmetrical vs. Asymmetrical) ANOVA on RTs. Degrees of freedom (1, 62).
*$p < .05$, **$p < .01$, ***$p < .001$.

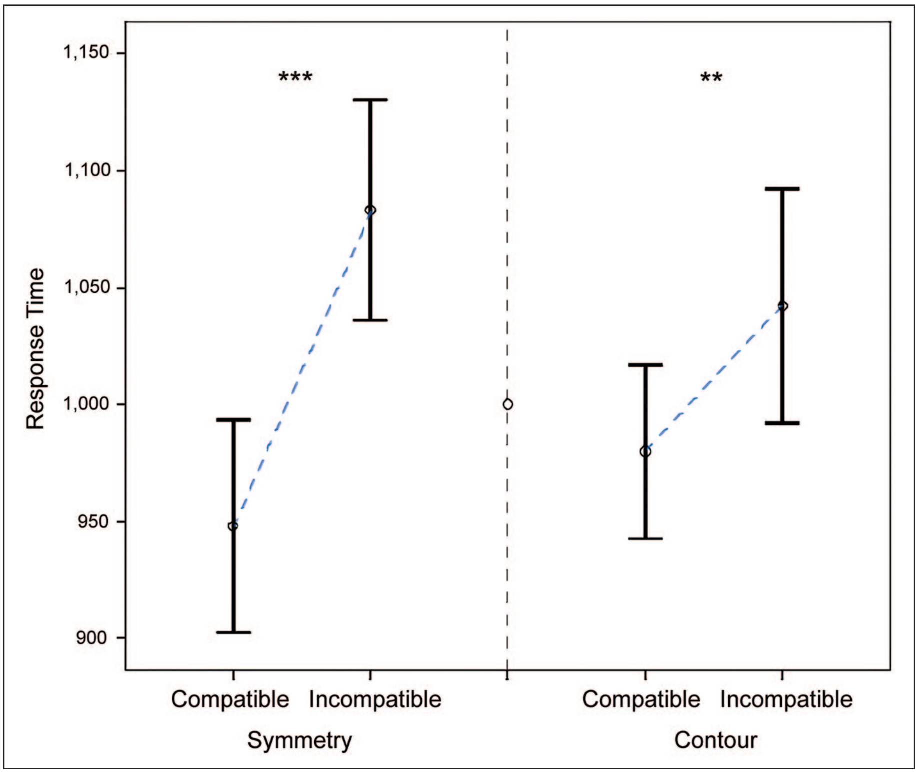

Figure 3. Mindset × Compatibility interaction. The difference between compatible and incompatible trials was higher in the symmetry mindset than in the contour mindset (***$p < .001$; **$p < .01$). Error bars represent 95% confidence intervals.

However, as the different mindset seems to be crucial in this interaction, the triple interaction analysis between the factors clarified this point.

The Mindset × Compatibility × Contour interaction showed an effect size that could be interpreted as fairly close to a medium effect based on Cohen's criteria, $\eta_p^2 = .052$, $\omega_p^2 = .036$, $r = .229$ (Cohen, 1994; Open Science Collaboration, 2015). In addition, this triple interaction clarified specific details about the previously explored Compatibility × Contour interaction. Figure 4 illustrates

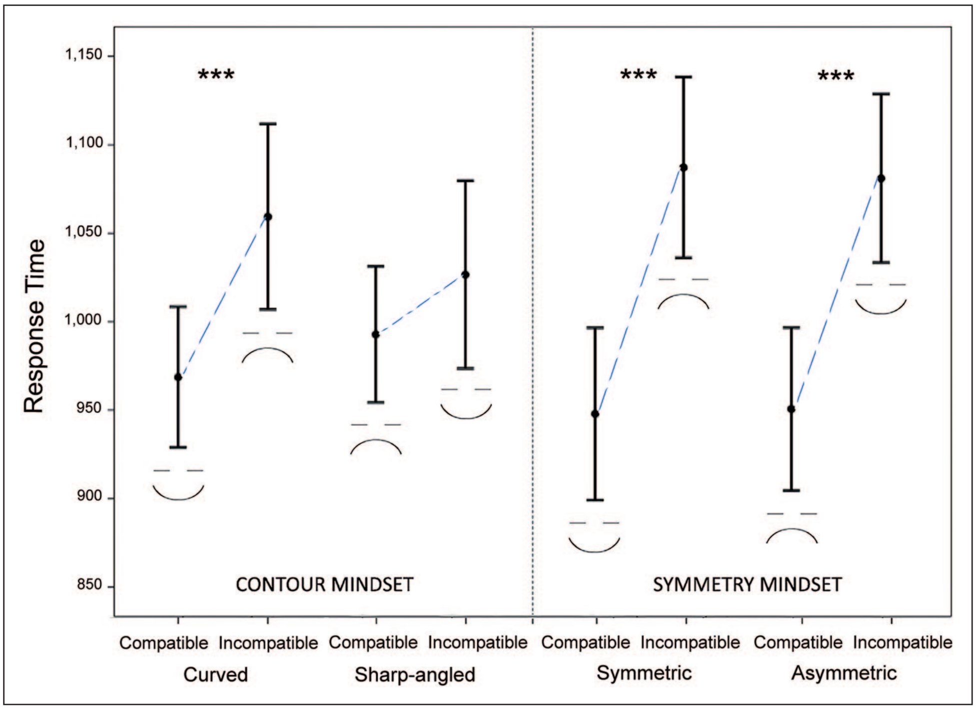

Figure 4. Mindset × Compatibility × Contour interaction. All differences between compatible and incompatible trials were significant (****p* < .001), except with sharp-angled stimuli. Error bars represent 95% confidence intervals.

the underlying reason for the triple interaction effect. Sharp-angled stimuli in the contour mindset was the only case in which the difference between compatible and incompatible trials was nonsignificant, $t(62)=1.531$, $p=.131$, $g=.176$, 90% CI = [0.016, 0.382]. When using curved stimuli, the difference was significant, $t(62)=4.385$, $p<.001$, $g=.49$, 90% CI = [0.294, 0.691]. In the symmetry mindset, both symmetric, $t(62)=7.069$, $p<.001$, $g=.7$, 90% CI = [0.511, 0.904], and asymmetric stimuli, $t(62)=6.621$, $p<.001$, $g=.697$, 90% CI = [0.498, 0.908] showed significant differences between compatible and incompatible conditions.

Contour × Symmetry was also significant. Participants were faster with curved than sharp-angled patterns in symmetric stimuli, $t(62)=2.79$, $p=.007$, $g=.14$, 90% CI = [0.058, 0.24], whereas they were faster with sharp-angled than curved patterns in asymmetric stimuli, $t(62)=2.38$, $p=.02$, $g=.12$, 90% CI = [0.035, 0.207] (Figure 5). RT was lower when the valences of the two visual properties were the same (positive: curved and symmetric; or negative: sharp-angled and asymmetric) than when they were different (curved and asymmetric, or sharp-angled and symmetric), regardless of mindset and response compatibility with the stimuli. In other words, the coherence of affective valences facilitated RT.

Finally, Mindset × Symmetry was also significant. Participants responded faster to asymmetric than to symmetric stimuli when mindset was contour, $t(62)=3.022$, $p=.004$, $\eta_p^2=.128$, but not when it was symmetry, $t(62)=.172$, $p=.864$, $\eta_p^2<.001$ (Figure 6).

Explicit task

We calculated a general explicit value from the average of the two explicit parts (contour and symmetry mindsets). The four kinds of stimuli showed significantly different general explicit values (Figure 7a). The most liked stimuli were the symmetric-curved ones. Their values were significantly higher than those of the symmetric-sharp patterns, $t(62)=7.88$, $p<.001$, $g=.965$, 90% CI = [0.724, 1.223]. The latter obtained significantly higher values than the asymmetric-curved patterns, $t(62)=8.35$, $p<.001$, $g=1.419$, 90% CI = [1.078, 1.785]. Finally, the asymmetric-curved patterns obtained also significantly higher values than the least liked patterns, the asymmetric-sharp ones, $t(629=7.3$, $p<.001$, $g=1.037$, 90% CI = [0.768, 1.336]. All the effect sizes were large.

As this explicit averaged value could be influenced by both mindsets, we ran again the explicit task without any specific mindset with 70 participants who had not performed the main experiment ($M_{age}=20.9$, 15 men). Explicit values were calculated from a single block without the mindset manipulation. Figure 7b shows that results (averages and *SD*s) were almost the same as the ones in the Figure 7a. They endorse using the general averaged value from the two explicit tasks.

With regard to the correlation between the aSRC results and the explicit measure, it is worth mentioning first that although SCR tasks are commonly claimed to capture implicit evaluations (Gawronski et al., 2020), the prevailing confusion regarding the implicitness construct

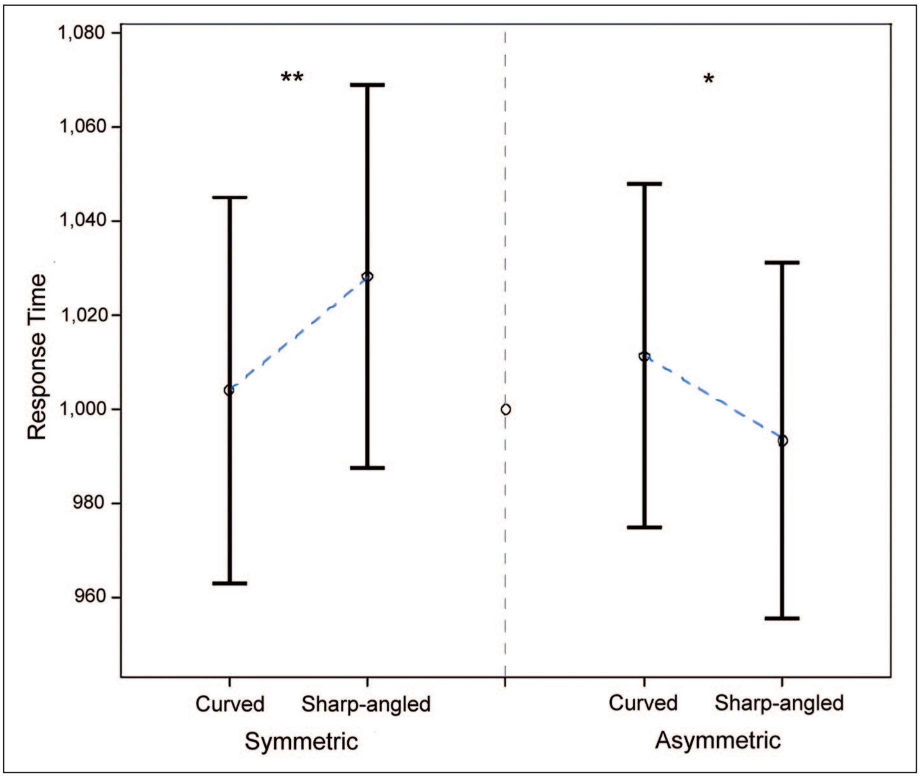

Figure 5. Contour × Symmetry features interaction (**$p < .01$; *$p < .05$). Error bars represent 95% confidence intervals.

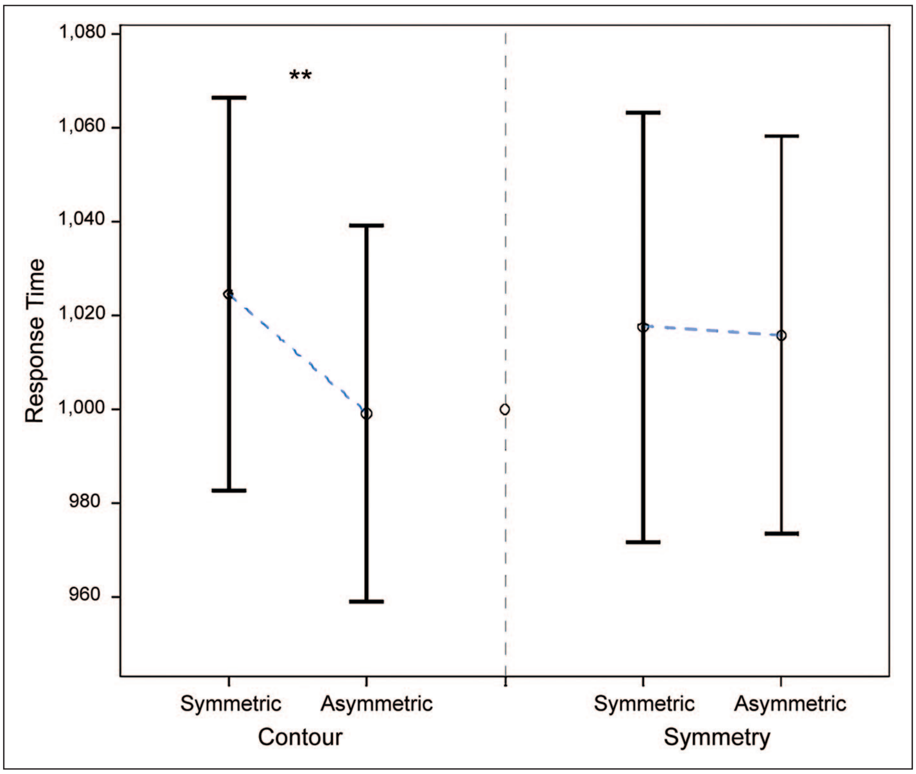

Figure 6. Mindset × Symmetry feature interaction (**$p < .01$). Error bars represent 95% confidence intervals.

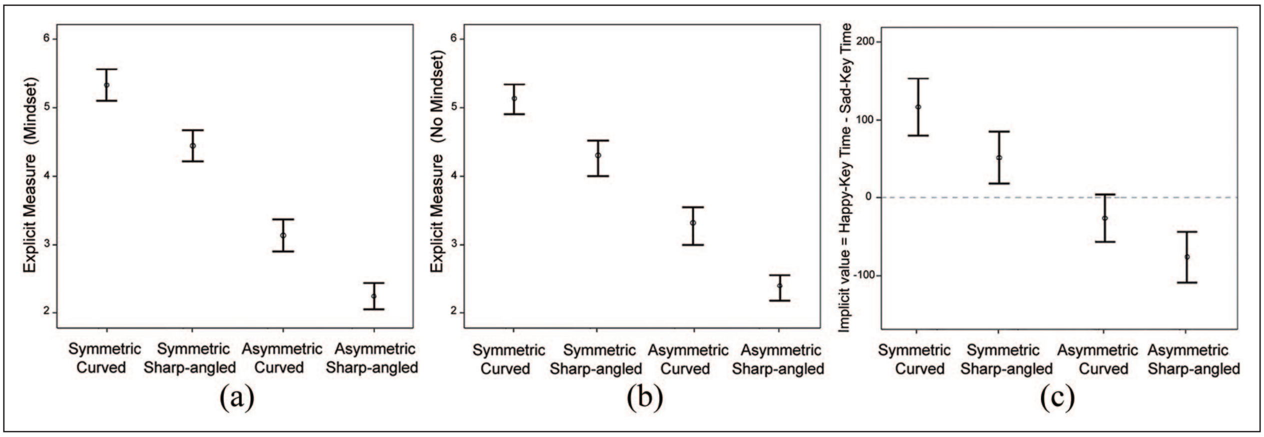

Figure 7. Explicit and implicit measures. (a) Explicit liking ratings of the four types of stimuli (all $ps < .001$). These values were calculated from the average of the two mindsets (contour and symmetry). (b) Supplementary explicit liking ratings calculated in another explicit task without mindsets. Both explicit liking results show highly similar patterns. (c) RTs differences between happy-key and sad-key to each type of stimuli. A positive value implies a correspondence with happy-key, whereas a negative value implies a correspondence with sad-key (all $ps < .05$). Error bars represent 95% confidence intervals.

(Corneille & Hütter, 2020) makes it advisable to specify that the term implicit refers here to indirect measures and largely automatic outcomes that capture efficient, autonomous, and probably unaware valuations—the valence of the attended stimulus is always irrelevant for response selection—with no further conceptual assumptions.

To compare explicit and implicit measures, we calculated a general implicit value. We subtracted RT for the sad-key from RT for the happy-key in every kind of stimulus. In this way, we obtained a value directly related to the happy-key RT and inversely related to the sad-key RT. As Figure 7c shows, the tendency of the implicit values was quite similar to the explicit values in Figure 7a and b. The implicit values with symmetric-curved stimuli were significantly higher than the values with symmetric-sharp ones, $t(62)=2.69$, $p=.009$, $g=.463$, 90% CI = [0.172, 0.763]. The values of the latter were also significantly higher than the values with asymmetric-curved stimuli, $t(62)=2.97$, $p=.004$, $g=.603$, 90% CI = [0.258, 0.958]. Finally, the difference between the values of these last stimuli and those of the asymmetric-sharp ones was also significant according to the Bonferroni correction, $t(63)=2.23$, $p=.03$, $g=.392$, 90% CI = [0.096, 0.695].

As we had an explicit measure for every mindset, we performed a similar analysis for each one. The most relevant change was that the difference between symmetric-sharp and asymmetric-curved stimuli decreased in contour mindset (Figure 8a) becoming nonsignificant, $t(63)=1.9$, $p=.063$, $g=.361$, 90% CI = [0.042, 0.685], and it increased significantly in symmetry mindset, $t(63)=11.21$, $p<.001$, $g=2.094$, 90% CI = [1.672, 2.554].

Regarding the implicit value, the big picture changed considerably (Figure 8b). This was due to symmetric-sharp and asymmetric-curved stimuli. Symmetric-sharp stimuli reached similar values to the asymmetric-sharp ones when mindset was contour, and similar values to the symmetric-curved ones when mindset was symmetry. On the contrary, asymmetric-curved stimuli reached similar values to symmetric-curved ones when mindset was contour and similar to asymmetric-sharp ones when mindset was symmetry. This showed that the implicit value depends quite a lot on mindset.

Finally, we calculated participants' correlations between explicit and implicit measures. As Table 2 shows, we found no significant results. Stimulus' correlation between the two measures was also nonsignificant, $r(48)=.204$, $p=.165$.

Discussion

Preference and visual features interaction

Our main goal was to test, from a nomothetic approach, the effects of the interaction between symmetry and curvature on the automatic hedonic valuation through a revised aSRC task. We defined symmetry and contour as different mindsets to carry out the tasks. Participants focused on one of two features in different parts. We used four types of stimuli that combined the two features. We also designed an explicit liking task with the same mindsets and stimuli, to compare implicit and explicit measures.

In the aSRC task, when symmetric or curved stimuli were associated with a happy face and asymmetric or sharp-angled stimuli were associated with a sad face, the trials were considered compatible. When symmetric or curved stimuli were associated with a sad face and asymmetric or sharp-angled with a happy face, the trials were considered incompatible. Participants responded faster to compatible trials than to incompatible trials both in symmetry and contour mindsets. This finding implicitly reveals

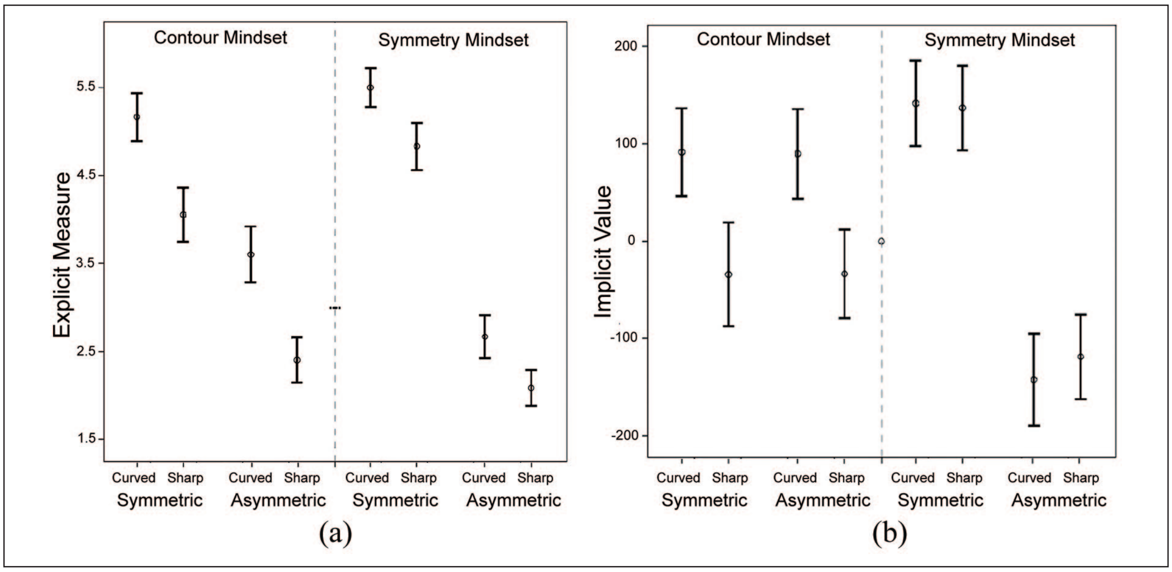

Figure 8. (a) The results of the explicit measure in contour and symmetry mindsets. Within each mindset, all differences were significant, except for the symmetric/sharp and asymmetric/curved stimuli in the contour mindset ($p = .063$). (b) The results of the implicit aSRC measure in contour and symmetry mindsets. Curved and symmetric stimuli showed higher implicit values in the contour and symmetry mindset, respectively. Error bars represent 95% confidence intervals.

Table 2. Correlations between explicit and implicit measures.

	Pearson's correlation	Significance (p)
General		
Symmetrical-curved	.118	.359
Symmetrical-sharp	–.172	.177
Asymmetrical-curved	–.102	.425
Asymmetrical-sharp	.098	.447
Contour mindset		
Symmetrical-curved	.127	.32
Symmetrical-sharp	–.011	.931
Asymmetrical-curved	.078	.545
Asymmetrical-sharp	–.071	.58
Curved	.122	.342
Sharp-angled	.051	.691
Symmetry mindset		
Symmetrical-curved	.099	.439
Symmetrical-sharp	.027	.834
Asymmetrical-curved	.161	.209
Asymmetrical-sharp	.101	.432
Curved	.097	.449
Sharp-angled	–.148	.248

a positive valence and a hedonic tone for symmetry and curvature without asking participants to report their judgements overtly. This hedonic component could be interpreted as preference. Preference for symmetry has been tested using other similar implicit paradigms with dot patterns (Makin et al., 2012) and configurations of black and white squares and triangles (e.g., Weichselbaum et al., 2018). Similarly, Palumbo et al. (2015) showed positive valence for curvature using curved and angular abstract polygons in an IAT and a mannikin task.

When comparing CIs of effect sizes, symmetry showed a large effect and curvature a medium effect. It suggests that symmetry's contribution to the hedonic tone is stronger than curvature's contribution. However, we cannot reject that this advantage of symmetry might be due to the kind of stimuli we used. In our stimuli, symmetry might stand out more than curvature, but it needs to be tested.

The triple interaction between symmetry, contour, and compatibility was not significant. Hence, we conclude that the hedonic tone in symmetry does not depend on the kind of contour, and the hedonic tone in curvature does not depend on whether or not the pattern is symmetric. Furthermore, these two visual features show a cumulative effect, as indicated in our implicit and explicit results. This is consistent with the hypothesis about the expected interaction between visual features if they had the same affective valence. The stimuli with the most positive valence were the symmetric-curved ones and the least were the asymmetric-sharp stimuli. In the middle, the symmetric-sharp stimuli had more positive valence than the asymmetric-curved ones. This fact emphasises the symmetry effect over the curvature effect.

In the aSRC task, what we interpret as hedonic valuation for symmetry and curvature only appeared clearly with the corresponding mindset, either symmetry or contour. Furthermore, the non-mindset condition did not diminish or increment the hedonic effect. Therefore, we can conclude that, according to our results, symmetry and curvature play no role in an aSRC task when they are ignored. These results are congruent with the evidence that implemental mindsets entail filtering of information, thus favouring the focus on the task at hand while decreasing the processing of irrelevant information (Fujita et al., 2007; Gollwitzer, 2012). Other results suggest that this increased selectivity may be due, at least in part, to a greater focusing of visual attention (Büttner et al., 2014). In addition, this evidence is in line with previous studies according to which the compatibility effect is greater when stimulus features are task-relevant than when they do not need to be processed to properly perform the task (Kornblum & Lee, 1995; Suchotzki et al., 2013).

On the other hand, contributions of symmetric and asymmetric stimuli to a most positive valence for symmetry were quite similar when the mindset was symmetry. However, when the mindset was contour, the contribution of sharp-angled stimuli was nonsignificant, and the most valence for curvature was mainly only caused by curved stimuli. Concerning the debate of whether the curvature effect is based on rejection of sharpness (Bar & Neta, 2006, 2007) or on a pure inclination for curvature (Gómez-Puerto et al., 2016; Palumbo et al., 2015), our findings indicated that preference for curvature is basically due to inclination for curved patterns, and the rejection of sharp-angled patterns is not substantial. However, we cannot rule out an implicit process based on sharpness rejection when people do not focus on the visual properties of the stimuli. Our finding comes from a task in which participants were clearly focused on contour and, in the symmetry mindset, the focus on symmetry might cancel a hypothesised implicit process of sharpness rejection.

We also obtained some striking findings about the RT related to specific stimulus properties and conditions. Participants responded equally fast to symmetric and asymmetric stimuli when they had to decide whether or not the stimuli were symmetric. However, they responded faster to asymmetric than to symmetric stimuli when they had to decide whether they were curved or sharp-angled. Conversely, some researchers suggested a temporal advantage to detect symmetric versus asymmetric patterns (Bornstein et al., 1981; Reber, 2002). This is consistent with the idea that perceptual fluency guides preference formation and even preference. The fluency hypothesis states that high fluency elicits positive affect and subjective beauty appraisals (Reber et al., 2004). Some studies showed that participants were quicker to respond to reflection symmetry than to random patterns (Bruce & Morgan, 1975; Makin et al., 2012). Nonetheless, participants were faster to detect asymmetric patterns than symmetric patterns in Royer's (1981) work. Also, Jacobsen and Höfel (2003) and Friedenberg (2018) showed that participants responded slower to reflected symmetric shapes than to asymmetric shapes on a rating scale task about beauty. Thus, our results about the symmetry assessment do not support the fluency hypothesis. Moreover, neither do our results about the curvature effect support the fluent hypothesis. There are different explanations for the discrepancy in results, but this was not the main objective of our study.

Our results suggested that symmetry and curvature are associated to positive (happy) schematic facial expressions, and asymmetry and sharpness are associated with negative (sad) schematic facial expressions. They also showed that participants were faster when both valences coincided—positive or negative—than when they did not coincide. The longer RTs when stimulus valences did not match (symmetric-sharp or asymmetric-curved) might be associated with the need to solve the dual-valence representation associated with surprised expressions that predict either positive or negative outcomes (Neta & Whalen, 2010). Another perspective to explain these results stems from the idea of interference when the level of the other property—contour or symmetry—does not coincide in valence with the one that the participant is responding to. Anyway, the correspondence of the faster response when the two affective positive dimensions and the highest liking in this kind of stimuli could be interpreted as a further proof of the correspondence between implicit positive valence and explicit preference.

Implicit hedonic tone and explicit preference

When comparing the four kinds of stimuli, the general pattern was quite similar in the implicit aSRC and the explicit task. However, this pattern changed when we included the mindset factor. Moreover, all correlations between implicit and explicit measures were nonsignificant.

Several authors reported low correlations between implicit and explicit measures (e.g., Hofmann et al., 2005). Hofmann et al. (2005) indicated that correlations increased as a function of (a) increasing spontaneity of explicit measures and (b) increasing conceptual correspondence between both measures. It is consistent with the assumption that implicit measures primarily reflect automatic associations, whereas explicit measures depend on the effortful retrieval of information from memory. Explicit measures might reflect automatic associations to a greater extent when participants do not have the possibility to retrieve additional information from memory. In our case, if the presentation time had been shorter in the explicit measures, the associations would have been more automatic and, consequently, the correlations could have been higher. For example, Corradi et al. (2018) showed that explicit preference for curvature changed depending on presentation time.

Regarding the possibility of the lack of conceptual correspondence between the two measures, the happy/sad dimension might not be the most precise approach to transfer the feeling produced by curved and sharp-angled contours, respectively. In this regard, other dimensions such as happy/angry, pleased/unpleased, or satisfied/unsatisfied need to be tested because they might show higher correspondence between the two measures.

Nosek (2005) and Nosek and Smyth (2007) indicated that implicit and explicit evaluations appear to be distinct constructs, with a relationship moderated by intrapersonal and interpersonal evaluative features. However, distinct implicit and explicit constructs do not rule out the possibility that the two constructs derive from common evaluative content (Nosek & Smyth, 2007). Nosek (2005) suggested that the relationship between implicit and explicit evaluations is mainly moderated by (a) the effortful presentation for personal or social purposes (self-presentation), (b) the vigour of the evaluations (strength), (c) the extent to which evaluations are represented with a simple, bipolar structure (dimensionality), and (d) the extent to which one's evaluation is perceived as distinct from normative responses (distinctiveness).

Following Nosek (2005) suggestions, three possibilities might explain the lack of correspondence between our measures. One explanation might be that they are not strong evaluations. Preference for symmetry and curvature, using abstract patterns, are not personally important, highly familiar, frequently thought about, stable, extreme, and unambivalent, as Nosek (2005) defined the strength factor. In this regard, meaningful stimuli might elicit stronger decisions and, hence, implicit and explicit correlations could be significant. According to the self-presentation factor, another possibility is that explicit values can be deliberately increased because of the particular context, while implicit values may not be altered. Thus, we found that the effect sizes of the explicit measure were higher than those from the implicit measure. Finally, it is possible that preference for symmetry and curvature are not bipolar continuums (dimensionality). For instance, liking symmetry stimuli does not imply disliking asymmetry. Bipolar evaluations are automatically activated more readily and consistently than evaluations not conforming to that structure (Nosek, 2005).

Limitations

The analyses were employed to derive group comparisons, that is, it is a nomothetic study. However, some studies have shown substantial individual differences on preference for symmetry (Jacobsen & Höfel, 2002) and preference for curvature (Corradi et al., 2019). Therefore, it is necessary to complement our study with an idiographic approach. Furthermore, we used a specific kind of stimuli, that is, meaningless patterns. Therefore, our approach can be further developed using other kind of stimuli, in order to support the evidenced contribution of symmetry and curvature to preference.

Conclusion

We explored the interaction between two visual features that shape initial visual preference, using implicit and explicit measures with two mindsets, symmetry and contour. We found an implicit association of curvature and symmetry with positive hedonic tone. Symmetry and curvature showed cumulative effects on preference in the explicit task and positive valence or hedonic tone in the implicit task. Moreover, we determined that the hedonic tone for curvature does not depend on symmetry, and the hedonic tone for symmetry does not depend on the kind of contour. Symmetry showed a larger effect than curvature on positive valence and preference. Our results also suggest that the curvature effect is mainly caused by the inclination for curved stimuli and not by the rejection of sharp-angled stimuli. Finally, we did not find any correlation between explicit and implicit measures, supporting Nosek's (2005) suggestion that they might be distinct constructs using different processes and representations. Altogether, the design of implicit/explicit methods and the use of mindset tasks provide a constructive and flexible approach to study how stimulus features interact.

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ORCID iDs

Erick G Chuquichambi https://orcid.org/0000-0001-5389-283X

Guido B Corradi https://orcid.org/0000-0001-9163-6829

Data accessibility statement

The dataset generated and analysed during the current study is available on the Open Science Framework: https://osf.io/kh4t3/.

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3.4. Shape familiarity modulates preference for curvature in drawings of common-use objects

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Shape familiarity modulates preference for curvature in drawings of common-use objects

Erick G. Chuquichambi[1], Letizia Palumbo[2], Carlos Rey[1] and Enric Munar[1]

[1] Human Evolution and Cognition Group (EvoCog), University of the Balearic Islands, Palma, Balearic Islands, Spain
[2] Department of Psychology, Liverpool Hope University, Liverpool, United Kingdom

ABSTRACT

Drawing is a way to represent common-use objects. The contour of an object is a salient feature that defines its identity. Preference for a contour (curved or angular) may depend on how familiar the resulting shape looks for that given object. In this research, we examined the influence of shape familiarity on preference for curved or sharp-angled drawings of common-use objects. We also examined the possibility that some individual differences modulated this preference. Preference for curvature was assessed with a liking rating task (Experiment 1) and with a two-alternative forced-choice task simulating approach/avoidance responses (Experiment 2). Shape familiarity was assessed with a familiarity selection task where participants selected the most familiar shape between the curved and the angular version for each object, or whether both shapes were equally familiar for the object. We found a consistent preference for curvature in both experiments. This preference increased when the objects with a curved shape were selected as the most familiar ones. We also found preference for curvature when participants selected the shape of objects as equally familiar. However, there was no preference for curvature or preference for angularity when participants selected the sharp-angled shapes as the most familiar ones. In Experiment 2, holistic and affective types of intuition predicted higher preference for curvature. Conversely, participants with higher scores in the unconventionality facet showed less preference for the curved drawings. We conclude that shape familiarity and individual characteristics modulate preference for curvature.

Subjects Neuroscience, Psychiatry and Psychology
Keywords Preference, Curvature, Drawings, Common-use objects, Familiarity, Individual differences

INTRODUCTION

Common-use objects are perceived as utilitarian, familiar and hedonic products (*Wang, Yu & Li, 2019*). These characteristics influence how we interact with them daily. For instance, utility, familiarity and/or hedonism might be factors that contribute to generally preferring common-use objects with curved contours over sharp-angled ones (*Bar & Neta, 2006*; *Bar & Neta, 2007*; *Munar et al., 2015*). Preference for curvature was shown using drawings of car interiors (*Leder & Carbon, 2005*), pictures of windows (*Naghibi Rad et al., 2019*), furniture (*Dazkir & Read, 2012*), product packaging (*Westerman et al., 2012*), exterior

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Corresponding author
Erick G. Chuquichambi, erik.chuquichambi@uib.es

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façades (Ruta et al., 2019) and interior architectural environments (Van Oel & Van den Berkhof, 2013; Vartanian et al., 2013; Vartanian et al., 2017), among others. While most of these stimuli involve representational content, preference for curvature was also found using non-representational art-related stimuli such as abstract artworks (Ruta et al., 2021) or abstract shapes and patterns (Bertamini et al., 2016; Bertamini et al., 2019).

Previous studies suggested that shared preferences are more usual with representational stimuli than abstract stimuli (Vessel & Rubin, 2010; Schepman, Rodway & Pullen, 2015; Schepman et al., 2015). Rodway et al. (2016) proposed that liking for representational stimuli is influenced by associations developed with the subject matter or semantic content of the picture. Therefore, our experience with the representational content of drawings or with the way an object is represented might also make preference for these stimuli more systematic and predictable. Skilled artists design representational drawings with relative ease (Kozbelt et al., 2010). On the one hand, the design process involves decisions about proportions, shading, lines, or colors, among others. On the other hand, the design process also involves implicit constraints such as the objects' functionality and usability, and sometimes even the cost of production (Lawson, 1980; Kavakli et al., 1999; Bertamini & Sinico, 2019).

Preference for curvature and familiarity

The consistency of visual preference for the representational content of stimuli highlights its association with familiarity (Reber, Winkielman & Schwarz, 1998; Reber, Wurtz & Zimmermann, 2004). Berlyne (1971) considered that familiarity strongly influences the psychobiological mechanisms underlying aesthetic experiences. Therefore, increased exposure to specific visual features might also modulate the potential preference for the same visual features. In this regard, some studies suggested that curved contours are more frequent in natural scenes than sharp-angled ones (Koenderink, 1984; Hoffman & Singh, 1997). Ruta et al. (2019) used a dynamic computational model of the visual cortex and a model that characterizes discomfort in terms of adherence to the statistics of natural images (Penacchio, Otazu & Dempere-Marco, 2013; Penacchio & Wilkins, 2015) to analyze the statistical properties of drawings of architectural façades with different contour types (curved, mixed, sharp-angled and rectilinear). They found that stimulus preference was related in both models and it matched the behavioural findings of preference for façades. Therefore, they suggested that the link between the statistical properties of natural scenes and preference for curvature might have evolved from human interaction with natural environments. Other studies suggested a faster speed of processing smooth contours over angular ones (Bertamini, Palumbo & Redies, 2019; Chuquichambi et al., 2020). Bertamini, Palumbo & Redies (2019) argued that this advantage may be explained because curved features tend to match the statistics of the natural environment in which the visual system has evolved. However, preference for curvature may also be a context-specific effect, and not extend to all natural environment stimuli (Hůla & Flegr, 2016).

The influence of familiarity on preference might be also related to the proximity of an object to the category prototype. In general, we would expect a link between typicality and familiarity (Hekkert, Snelders & Wieringen, 2003). Whitfield & Slatter (1979) investigated whether proximity to the prototype influenced aesthetic choice using images of furniture with different styles. These authors found that the furniture and styles selected by participants in their similarity task consistently corresponded to those selected in their aesthetic task. Influenced by these results, *Whitfield & Slatter (1979)* developed the preference for prototypes theory suggesting that aesthetic choice reflects categorization and prototypicality. That is, prototypicality may act as an influential determinant of preference for everyday objects (*Whitfield, 1983*). *Winkielman et al. (2006)* proposed that part of preference for prototypicality arises from a general mechanism linking fluency and positive affect. Along with prototypicality, these authors suggested that other factors might also act as fluency-enhancing variables and, therefore, explain the prototypicality-attractiveness relationship. In this sense, preference for objects with curved contours might be one of these variables because curvature facilitates processing fluency (*Corradi & Munar, 2020*).

Drawings of common-use objects are characterised by meaningful and familiar content (*Hekkert, Snelders & Dirk, 1995*; *Hekkert, Snelders & Wieringen, 2003*). They involve the perceiver's previous knowledge and momentary perceptual experience (*Leder et al., 2004*). Given that people might be more exposed to curved contours than to sharp-angled ones in daily life, the potential preference for curved drawings of common-use objects might be modulated or explained by the degree of familiarity of these objects. However, this relationship might be also modulated by the artistic reproduction of drawings.

Drawings as artistic works

Drawings are associated with innovation and creativity because of their art-related nature (*Purcell & Gero, 1998*). The experience of drawing embodies abstract and high-level design ideas, and allows some degree of uncertainty about how to represent the physical attributes of the object (*Gross et al., 1988*). These characteristics might differentiate preference for representational drawings from preference for more realistic (e.g., photographs) or more abstract stimuli (e.g., irregular polygons). Contrary to representational stimuli, *Bornstein (1989)* found that abstract paintings, drawings, and matrices did not show a strong mere exposure effect. This effect proposes that affect increases with repeated unreinforced exposure of a stimulus, and therefore, familiarity (*Zajonc, 1968*). *Leder (2001)* also showed that repeated exposure had little effect on art-related stimuli. Instead, he suggested that familiarity-liking relations were weakened by knowledge and were greater in spontaneous judgements. These findings are compatible with the fact that novelty is an important factor in the appreciation of fine arts, where the seeking for novelty is a dominant force in its development (*Martindale, 1990*). *Hekkert, Snelders & Wieringen (2003)* showed typicality and novelty as equally effective predictors to explain aesthetic preference of consumer products (e.g., telephones, cars, etc.). They suggested that there should be a balance between novelty and typicality in the design of common-use objects. Interestingly, *Park, Shimojo & Shimojo (2010)* found segregation of preference across objects' categories, with familiarity dominant in faces, and novelty dominant in natural scenes. Given this context, the interaction between the representational content and art-related characteristics of drawings of common-use objects might contribute to understanding the role of familiarity in predicting aesthetic judgements (*Sluckin, Hargreaves & Colman, 1982*).

Individual differences and preference for curvature

Individual differences also modulate aesthetic judgements (*Child, 1962*; *Child, 1965*; *Leder et al., 2019*). However, the influence of individual differences in preference for curvature diverges between studies. *Silvia & Barona (2009)* investigated the role of artistic expertise in preference for curvature using arrays of circles and hexagons, and asymmetrical random polygons. Although they found an interaction between art training with angular stimuli, this interaction changed depending on the specific stimuli set. *Vartanian et al. (2017)* also found divergent results in preference for curvature among experts (architects or designers) and non-experts. They presented these participants with images of curvilinear and rectilinear architectural interior spaces in a beauty judgement task and an approach-avoidance decision task. Despite that the experts found curvilinear spaces more beautiful than rectilinear ones, contour did not affect their willingness to enter or exit these spaces. Conversely, contour had no effect on judgements of beauty among nonexperts, but they were more likely to enter curvilinear spaces than rectilinear ones. However, a more recent study did not confirm preference for curved interior spaces with quasi-experts in industrial design (*Palumbo et al., 2020*), hence highlighting that individual differences might also depend on the specific training received in the area of expertise. *Cotter et al. (2017)* also reported that artistic expertise, a personality trait such as openness to experience, along with other cognitive traits (i.e., holistic thinking) predicted higher preference for curvature using irregular polygons, but not using arrays of circles and hexagons. *Corradi et al. (2019a)* suggested that aesthetic sensitivity to curvature coexists with a remarkable individual variation on people's judgements. They presented real objects and abstract designs to art and non-art students in a two-alternative forced-choice task. They also were interested in the role of sex, openness to experience and artistic expertise. Both groups of students preferred the curved stimuli but none of the individual variables showed significant results.

The present study

In this study, we examined preference for contour (curved or angular) in two experiments using drawings of common-use objects. The drawings consisted of pairs of the same object with a curved and a sharp-angled version created by quasi-expert students in Design as described in *Bertamini & Sinico (2019)*. They were rated by non-experts for seven characteristics, confirming an association between curvature and beauty. In the current experiments, we examined whether the selection of pairs based on the familiarity of the shape of the objects, and specific individual differences, would modulate preference for contour. Each experiment had two tasks. The first tasks were a liking rating task for the drawings in Experiment 1, and a two-alternative forced-choice (2AFC) task simulating approach/avoidance responses in Experiment 2. The second task was a subjective familiarity selection task for the shape of the objects in both experiments. In this task, participants categorized the object pairs in three groups: (a) the pairs in which the curved shape was the most familiar, (b) the pairs in which the sharp-angled shape was the most familiar, and (c) the pairs in which both shapes were equally familiar. This way, we could analyse preference for curvature in each group. At the end of the experimental tasks, all participants were administered a set of individual measures: a Spanish adapted scale of Art interest and Art knowledge (Chatterjee et al., 2010), the Openness to experience Scale from the NEO-FFI (McCrae & Costa, 2004), the items of the Unconventionality facet from the HEXACO personality test (Lee & Ashton, 2004), and the Types of Intuition Scale (TIntS) (Pretz et al., 2014).

First, we hypothesized that participants would prefer the curved object drawings in both experiments because preference for curvature has shown to be consistent across different stimuli and experimental tasks (Palumbo & Bertamini, 2016; Chuquichambi et al., 2021). Second, we expected that the curved contours would be perceived as the most familiar because of the predominant role of curvature on shape's perception (Pasupathy & Connor, 2002) and its suggested higher exposure in nature (Koenderink, 1984; Hoffman & Singh, 1997; Bertamini, Palumbo & Redies, 2019; Ruta et al., 2019). Third, familiarity selection for curved shapes might largely explain preference for curved drawings or only influence this preference. That is, we could find that when the curved shapes are selected as the most familiar, the higher the preference for the curved drawings, or we could find preference for the curved drawings without necessarily perceiving the curved shapes as the most familiar. Fourth, according to the divergences between studies, the variation in people's judgements and stimulus characteristics might explain the inconsistent role of some individual differences in preference for curvature (Corradi et al., 2019b). Therefore, the current study aimed to assess to what extent preference for curvature might be explained by familiarity for the shape with which the objects were represented in the drawings and whether this would be modelled by individual differences.

EXPERIMENT 1

Materials & methods

Participants

Forty-nine adult students (41 female, $M_{age} = 21.3$, $SD_{age} = 4.95$) at the University of the Balearic Islands (UIB) volunteered to participate in the experiment. All participants reported normal or corrected to normal vision and were naïve concerning the experimental hypothesis. They provided written informed consent before the experiment. The experiment was conducted following the code of practice of the APA guidelines, and received ethical approval from the Committee for Ethics in Research (CER) of the UIB (Ref: IB 3828/19 PI).

Apparatus and materials

Ninety drawings of familiar objects were selected from the IUAV image database (https://osf.io/cx62j/) (Bertamini & Sinico, 2019). The selected stimuli consisted of 45 pairs of drawings. Each pair represented the same object, a curved and a sharp-angled version. These pairs were selected considering that the curved and the sharp-angled versions were similar in terms of size, compression ratio of the file (an index used as a measure of image complexity; Forsythe, Mulhern & Sawey, 2008; Palumbo et al., 2014), perceived lightness, weight, or style according to the data reported by Bertamini & Sinico (2019). On the other hand, some pairs of drawings differed in how they were made. Thirty pairs were hand-made and 15 were computer-made. Similarly, 15 pairs were shaded and 30 were not shaded.

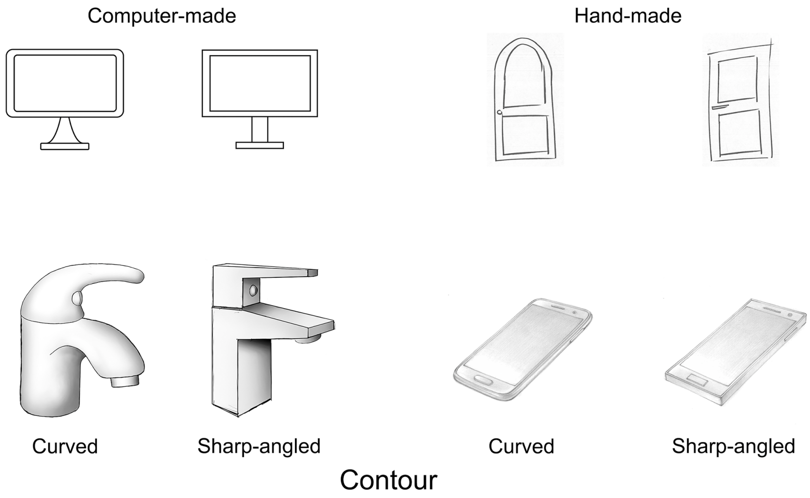

Figure 1 Examples of the pairs of drawings (IUAV image database). Each pair has a curved and sharp-angled version. Left-side, computer-made. Right-side, hand-made. Top, not shaded. Bottom, shaded.
Full-size DOI: 10.7717/peerj.11772/fig-1

Lastly, the apparent position of the objects in relation to the viewer corresponded to a frontal view in 24 pairs, and to a $\frac{3}{4}$ view in 21 pairs. Out of the hand-made drawings, 13 pairs were shaded, 17 pairs were not shaded, 13 pairs were in $\frac{3}{4}$ view, and 17 pairs were in frontal view. Out of the computer-made drawings, 2 pairs were shaded, 13 pairs were not shaded, 8 pairs were in $\frac{3}{4}$ view, and 7 pairs were in frontal view. The curved and the sharp-angled version of each pair had the same Category, Shading and Position. The pairs of stimuli were equalized in size and had 300 dpi resolution. Every stimulus was presented framed on an outline of 600 pixels height, and 600 pixels width. (Fig. 1).

We used the same drawings in the liking rating task and the familiarity selection task. The liking task recorded ratings of each drawing using a horizontal sliding bar from 0 to 100. The ends of the bar had the labels "*I don't like it*" (0) on one side, and "*I like it very much*" (100) on the other side (Fig. 2A). Each stimulus was presented on the centre of the screen until the participant had responded on the sliding bar using the mouse. The task had 8 practice trials corresponding to 4 additional pairs of drawings from the image database, and 90 experimental trials corresponding to the 45 stimuli pairs. Trial sequence was randomized.

The familiarity selection task presented each pair of drawings simultaneously, one on the left and the other on the right side of the screen, until the participant responded. The question was "*Which shape is the most familiar for this object?*" There were three-alternative responses labelled as left, equal, and right. If they chose the shape of the left-side object as the most familiar, they had to press the left key. If they chose the shape of the right-side object, they had to press the right key. They could also choose the shape of both objects as equally familiar by pressing the central key. The task had 8 practice trials and 45 experimental trials corresponding to the 45 pairs. Left-side and right-side presentation and trial sequence were randomized.

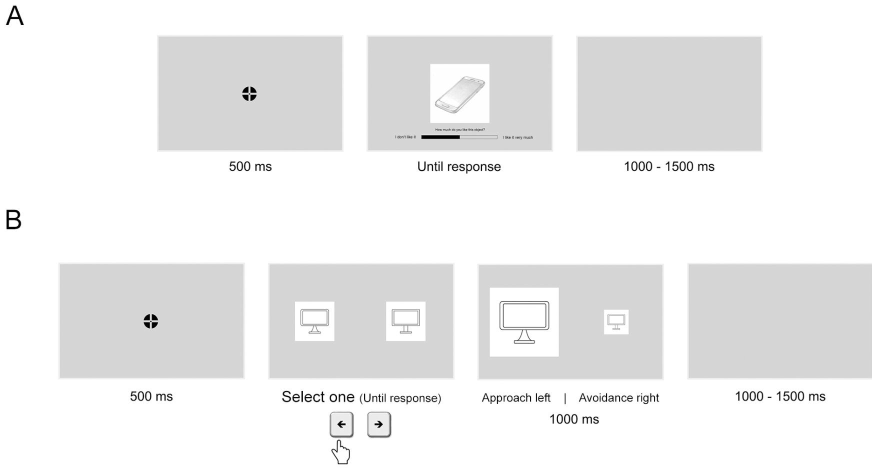

Figure 2 **Trials sequence in the preference tasks of experiments 1 and 2.** (A) An example trial in the liking rating task from Experiment 1. (B) An example trial in the two-alternative forced-choice task from Experiment 2. The example shows that the left object was selected. In the next slide, the left object (selected) and the right object (non-selected) simulated approach and avoidance actions, respectively.
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Four questionnaires were administered. The first was an Art interest and Art knowledge scale adapted from *Chatterjee et al.*'s (*2010*) Art Training, Interest and Activities Scale. This scale was used in previous studies of aesthetic sensitivity (e.g., *Corradi et al., 2019b*). It consists of eight items with a 0–6 Likert scale. Five items (1–5) measure interest in art, and three (6–8) measure formal education in art. The second questionnaire was the Openness to experience Scale of the NEO-FFI (*McCrae & Costa, 2004*). It consists of twelve items rated on a scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). The third questionnaire consists of four items about the Unconventionality facet of the Openness to experience domain from the HEXACO 100 Personality Inventory-Revised (*Lee & Ashton, 2004*). We included this measure because *Cotter et al. (2017)* showed that higher scores on the Unconventionality facet predicted greater preference for curvature using geometrical patterns. Finally, participants completed the Types of Intuition Scale (TIntS) to examine whether the way people make decisions and solve problems modulates preference for drawings (*Pretz et al., 2014*). This scale consists of 23 items (e.g., "I am a 'big picture' person", "I tend to use my heart as a guide for my actions") rated on a scale ranging from 1 (*definitely false*) to 5 (*definitely true*). The items are grouped into four subscales: Holistic Abstract (HA, thinking about a problem in abstract terms), Holistic Big Picture (HB, focusing on the entire problem rather than details of the situation), Inferential (I, making decisions based on automatic, analytic processes), and Affective (A, making decisions by relying on emotional reactions to a situation). The scores of the questionnaires are reported in Table 1.

All tasks were designed with OpenSesame (3.2) software (*Mathôt, Schreij & Theeuwes, 2012*). They were implemented in computers equipped with Intel i5 processors and 21–inch screens set at 1,920 × 1,080 pixels.

Table 1 Descriptive statistics for the individual differences measures of Experiment 1 ($n = 49$). Score ranges: Art interest (0–30), Art knowledge (0–18), Openness to experience (11- 60), Unconventionality (4–20), HA (3–15), HB (4–20), I (8–40), A (8–40).

Variable	Mean	Median	SD	Min –Max
Art interest	10.6	12	5.44	1 –20
Art knowledge	1.43	1	2.03	0 –11
NEO: Openness to experience	47.4	48	5.94	30–59
HEXACO: Unconventionality	3.61	3.75	.57	2.25–5
TIntS: Holistic Abstract (HA)	8.4	8	2	3–14
TIntS: Holistic Big picture (HB)	13.3	13	2.47	8–19
TIntS: Inferential (I)	28.5	29	3.4	19–35
TIntS: Affective (A)	25	25	5.03	16–36

Procedure

The experimental session was carried out at the Psychology Laboratory of the UIB, using isolated cabins and individual computers with the same software and light conditions. Participants were welcomed at the laboratory and they provided written informed consent. They received verbal and written instructions before starting each task. The liking task was the first one. Participants were told that a drawing would be presented at the centre of the computer screen. They had to indicate how much they liked the drawing with a mouse click on the horizontal sliding bar. Next, participants carried out the familiarity selection task. They were told that pairs of drawings would be presented on the computer screen, one on the left and the other on the right side of the screen. They had to select which shape was the most familiar for the object in the drawing, or whether both shapes were equally familiar, by pressing the appropriate key. After these tasks, participants filled in the four questionnaires. The experimental session lasted about 20 min. Finally, participants were debriefed and thanked.

Data analysis

Data analysis was carried out with the R environment for statistical computing (*R Core Team, 2018*). Participants' responses in the liking task, the familiarity selection task and questionnaires were analysed by means of linear mixed effects models (*Hox, 2010*; *Snijders & Bosker, 2012*). These models account simultaneously for the between-subject and within-subject effects of the independent variables (*Baayen, Davidson & Bates, 2008*). They have been previously used to analyse preference judgements and individual differences (e.g., *Corradi et al., 2019a*; *Corradi et al., 2019b*). The 'lmer' function from the lme4 package was used to fit the models (*Bates et al., 2015*). The afex package (*Singmann et al., 2016*), with the likelihood ratio test, was used to produce the inferential statistics and p values. The lsmeans package was used to obtain predicted means for the fixed effects (*Lenth, 2016*). Participant and Stimulus were included as random effects in all models. Model selection was carried out considering model fit indices and following *Barr et al.*'s (*2013*) and *Brauer & Curtin*'s (*2018*) guidelines to choose the maximal random-effects structure justified by the experimental design. Finally, we performed a study of influential cases based on Cook's distance (Cook's D) in each model. This measure evaluates each participant's influence on the results by examining the impact of its removal from the data set (*Corradi et al., 2018*).

Results

We considered three models. The first model tested preference for curvature and its relation to the other stimulus properties: computer-made versus hand-made, shaded versus not shaded, and frontal versus $\frac{3}{4}$ view. The second model analysed the relationship between preference for curvature and familiarity selection. The third model tested the influence of the individual measures (i.e., personality and art expertise) on the liking ratings related to preference for curvature.

The first model aimed to predict liking ratings based on Contour (curved vs. sharp-angled), Category (computer-made vs. hand-made), Shading (shaded vs. not shaded), and Position (frontal vs. $\frac{3}{4}$ view) as factors of fixed effects. We also included the interactions between Contour and Category, Contour and Shading, and Contour and Position. The best model, according to models fit indices, included random slopes within participant random effect. Influential cases analysis revealed no influential cases whose value exceeded the recommended cut-off point, which was .090. Participants significantly liked the curved drawings ($M = 55.1$, 95% CI [50–60.2]) more than the sharp-angled ones ($M = 50.4$, 95% CI [45.4–55.4]), $\beta = 3.51$, SE = 1.5, t(92.8) = 2.31, $p = .023$, 95% CI [.53–6.5] (Fig. 3A). There was no significant interaction of Contour ×Category, $\beta = -1.94$, SE = 1.52, t(4217) = −1.28, $p = .20$, 95% CI [−4.9, −1.04], Contour ×Shading, $\beta = 1.85$, SE = 1.6, t(364) = 1.16, $p = .24$, 95% CI [−1.3–5], or Contour ×Position, $\beta = -2.45$, SE = 1.4, t(4217) = −1.76, $p = .080$, 95% CI [−5.2–.30]. Participants also significantly liked the drawings with shading ($M = 61.7$, 95% CI [54–69.4]) more than the drawings with no shading ($M = 43.8$, 95% CI [38.3–49.3]), $\beta = 17$, SE = 4.64, t(64) = 3.66, $p < .001$, 95% CI [7.9—-26.1]. There was no significant difference between the hand-made ($M = 50.6$, 95% CI [45.5–55.6]) and the computer-made drawings, ($M = 55$, 95% CI [47.6–62.3]), $\beta = -3.4$, SE = 4.1, t(44) = -.83, $p = .41$, 95% CI [−4.6–11.4]. Similarly, liking ratings did not significantly differ between the drawings in frontal ($M = 50.7$, 95% CI [44.5–57]) and $\frac{3}{4}$ view ($M = 54.8$, 95% CI [48.8–60.7]), $\beta = -2.82$, SE = 3.7, t(44) = -.75, $p = .45$, 95% CI [−10.1–4.5].

The familiarity selection task showed that the curved shapes were selected as the most familiar ones in a proportion of .49, the sharp-angled shapes were selected as the most familiar ones in a proportion of .22, and both shapes were selected as equally familiar in a proportion of .29. The second model included liking rating as the variable to be predicted, and Contour type and Familiarity as categorical fixed effects. The interaction between the two factors was also included, as our main objective was to examine the relationship between contour preference and familiarity. The three familiarity categories were included in the analysis as three levels: the curved shape selected as the most familiar, the sharp-angled shape selected as the most familiar, and both shapes selected as equally familiar. The best model included random slopes within participant and stimulus. Influential cases analysis revealed two influential cases exceeding the recommended cut-off point, which was .087. Therefore, these participants were excluded from the analysis. Results showed that the Contour × Familiarity interaction was significant when we considered the curved

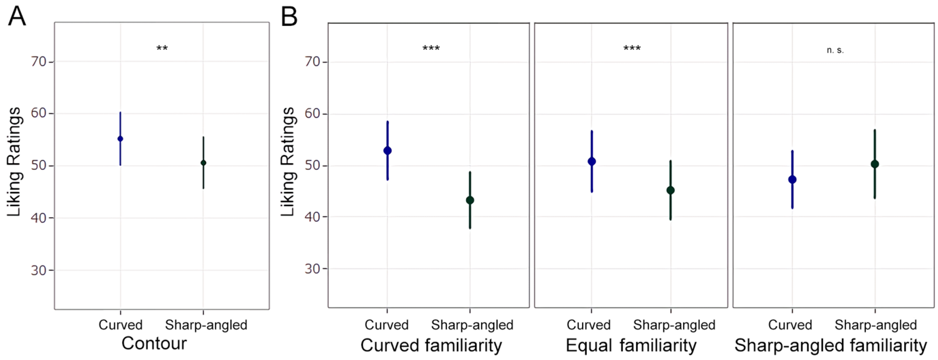

Figure 3 Liking ratings and familiarity selections of Experiment 1. (A) Mean liking ratings for the curved and sharp-angled drawings. (B) Mean liking ratings for the drawings within the three alternative responses of the Familiarity selection task. Left graphic represents familiarity selections for the curved shapes, middle graphic represents both shapes selected as equally familiar, and right graphic represents familiarity selections for the sharp-angled shapes. Each one of these graphics show mean liking ratings for the curved and sharp-angled drawings. The curved drawings were liked more when the curved shapes were selected as the most familiar ones, or when both shapes were selected as equally familiar, but not when the sharp-angled shapes were selected as the most familiar ones. Error bars represent 95% CI (** $p \leq .01$, *** $p \leq .001$, n.s.: not significant).

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and sharp-angled responses in the Familiarity factor, $\beta = 12.58$, SE = 2.22, t(82.5) = 5.67, $p < .001$, 95% CI [8.23–16.93]. Specifically, participants liked the curved drawings ($M = 52.9$, 95% CI [47.3–58.4]) more than the sharp-angled ones ($M = 43.3$, 95% CI [38, 48.7]) when the curved shapes were selected as the most familiar ones, $\beta = 9.6$, SE = 1.6, t(44) = 5.8, $p < .001$. Conversely, when the sharp-angled shapes were selected as the most familiar ones, liking ratings did not differ significantly between the sharp-angled drawings ($M = 50.3$, 95% CI [43.7–56.8]) and the curved ones ($M = 47.3$, 95% CI [41.8–52.8]), $\beta = 3$, SE = 2.1, t(23.7) = 1.4, $p = .16$ (Fig. 3B). The Contour ×Familiarity interaction was significant when we considered both shapes selected as equally familiar and the sharp-angled shapes selected as the most familiar ones, $\beta = 8.46$, SE = 2.2, t(79) = 3.79, $p < .001$, 95% CI [4.1–12.8]. This effect revealed that when both the curved and sharp-angled shapes were selected as equally familiar, participants still liked the curved drawings ($M = 50.8$, 95% CI [45, 56.6]) more than the sharp-angled ones ($M = 45.2$, 95% CI [39.5–50.8]), $\beta = 5.6$, SE = 1.5, t(25) = 3.6, $p = .0010$. Lastly, the Contour x Familiarity interaction also reached significance when we considered the curved shapes selected as the most familiar ones and both shapes selected as equally familiar, $\beta = 4.01$, SE = 1.87, t(102.1) = 2.15, $p = .034$, 95% CI [.36–7.67]. In conclusion, we found an effect of preference for curvature when the curved shapes were selected as the most familiar ones and when both shapes were selected as equally familiar. However, there was no effect of preference for contour when the sharp-angled shapes were selected as the most familiar ones.

Regarding the individual measures, we analysed whether they modulated liking ratings related to the curved and sharp-angled drawings. The model predicted liking ratings based on Contour and its interactions with Art interest, Art knowledge, Openness to experience, the Unconventionality facet, and TIntS subscales (HA, HB, I and A) as predictors. All continuous predictors were centred on the grand mean. The best model included random slopes within participant and stimulus. Influential cases analysis showed no influential cases whose value exceeded the recommended cut-off point, which was .10. Results revealed that participants who scored higher in the Holistic Big Picture Subscale (HB) showed higher liking ratings for all the drawings, $\beta = 1.3$, SE = .52, t(23) = 2.5, $p = .020$, 95% CI [.28–2.32]. All other effects and interactions were nonsignificant. All effects are included in Table S1 as supplementary material.

Discussion

Experiment 1 showed that participants liked the curved drawings more than the sharp-angled ones. This result supports the curvature effect (*Corradi & Munar, 2020*). Our results also reported an interaction between familiarity and curvature on shape preference. When the curved shapes were selected as the most familiar ones, the curved drawings were liked more than the sharp-angled drawings. This finding supports the role of familiarity in predicting aesthetic preference (*Verhaeghen, 2018*; *Chmiel & Schubert, 2019*). That is, the drawings with the shapes that were chosen as most familiar to represent the objects were liked more. However, we also found that when the shapes of the objects were selected as equally familiar, participants also liked the curved drawings more than the sharp-angled ones. Furthermore, when the sharp-angled shapes were selected as the most familiar ones, liking did not differ between the curved and sharp-angled drawings. Altogether, these findings suggest that familiarity of the shape with which the objects have been represented in the drawings modulates preference for curvature, but it does not completely explain participants' preference for the curved drawings.

Individual measures analysis showed that participants with higher scores in the Holistic Big Picture subscale liked all the drawings more than participants with lower scores. All the other measures did not significantly influence liking ratings. These findings are in line with studies suggesting an uncertain role of some individual measures on preference for curvature (*Corradi et al., 2019b*).

EXPERIMENT 2

Experiment 2 consisted of a 2AFC task simulating approach/avoidance responses (Fig. 2B). Approach/avoidance procedures have been previously used in preference for curvature research (*Vartanian et al., 2013*; *Palumbo, Ruta & Bertamini, 2015*). Participants carried out the same familiarity selection task and questionnaires as in Experiment 1. In the 2AFC task, each pair of drawings was presented on the screen until participants responded, as in previous studies (*Munar et al., 2015*; *Corradi et al., 2018*). However, although these studies reported preference for images of curved real objects in short and medium presentation times, the effect disappeared in the until-response condition. Similarly, these authors reported preference for curved abstract patterns in short and medium presentation times, but in this case, the effect increased in the until-response condition. *Palumbo & Bertamini (2016)* showed that preference for curvature was consistent across tasks using irregular shapes. Considering these studies and the results from Experiment 1, we expected that participants would prefer the curved object drawings more than the sharp-angled ones.

Table 2 Descriptive statistics for the individual differences measures of Experiment 2 ($n = 49$). Score ranges: Art interest (0–30), Art knowledge (0–18), Openness to experience (12 60), Unconventionality (4 20), HA (3–15), HB (4–20), I (8–40), A (8–40).

Variable	Mean	Median	SD	Min –Max
Art interest	10	9	6.22	0–26
Art knowledge	2.35	1	2.94	0–12
NEO: Openness to experience	46.3	45	5.53	36–58
HEXACO: Unconventionality	3.58	3.5	.58	2.5–5
TIntS: Holistic Abstract (HA)	7.94	8	2.21	3–13
TIntS: Holistic Big picture (HB)	12.8	12	2.55	7–20
TIntS: Inferential (I)	29.5	30	3.33	20–38
TIntS: Affective (A)	25.3	25	5.53	12–35

Furthermore, we expected that shape familiarity would also modulate preference for curvature.

Materials & Methods

Participants

Forty-nine adult students (35 female, $M_{age} = 26.3$, $SD_{age} = 6.5$) at the UIB volunteered to participate in the experiment. All participants reported normal or corrected to normal vision and were naïve concerning the experimental hypothesis. They provided written informed consent before the experiment and were treated following the code of practice of the APA guidelines. The study received ethical approval from the Committee for Ethics in Research (CER) of the UIB (Ref: IB 3828/19 PI).

Apparatus and materials

We used the same 90 drawings as in Experiment 1 (Fig. 1). They were presented both in the 2AFC task and the familiarity selection task. In the 2AFC task, each pair of stimuli was presented until response, a drawing on the left and the other on the right side of the computer screen (Fig. 2B). Participants were instructed to select one of the two object drawings, and instructions avoided the words 'liking', 'wanting' and 'preference' as in *Munar et al. (2015)* and *Corradi et al. (2018)*. Later, the selected drawing was enlarged to twice its previous size, while the non-selected one was shrunk to half its previous size at the same position for 1,000 ms. This action simulated an approach/avoidance behaviour (*Bamford et al., 2015*). As in Experiment 1, the 2AFC task had 8 practice trials with additional stimuli from the image database, and 45 experimental trials corresponding to the 45 pairs of drawings. Left-side and right-side stimulus presentation and trial sequence were randomized. The familiarity selection task and the set of questionnaires were the same as in Experiment 1. The scores of the questionnaires are reported in Table 2.

Procedure

The experimental session was carried out as in Experiment 1. Participants received verbal and written instructions before starting each task. First, they carried out the 2AFC task. They were told that they had to select one of two drawings presented on the screen using the right and left arrow keys. Then, the size of the selected drawing would be enlarged, and the size of the non-selected drawing would be shrunk. Next, they carried out the familiarity selection task receiving the same instruction as in Experiment 1. Lastly, they filled in the questionnaires using the same computer. The experimental session lasted about 20 min. Finally, participants were debriefed and thanked.

Data analysis

Analyses were carried out with the R environment for statistical computing (*R Core Team, 2018*). We mainly modelled responses by means of generalized linear mixed effects models given that the dependent variable in the 2AFC task was the kind of contour participants selected (curved or sharp-angled). The 'glmer' function from the lme4 package was used to fit the models (*Bates et al., 2015*). All models included Participant and Stimulus as random effects. Model selection was performed following the same considerations outlined in Experiment 1. Finally, we performed a study of influential cases in each model.

Results

We considered three analyses. First, we analysed preference for curvature and its relationship with the other stimulus characteristics. The second analysis was based on a model to test the relationship between preference for curvature and familiarity selection. The third analysis examined the influence of the individual measures on preference for curvature.

Previously, we carried out a t-test on the preference for curvature as compared to angularity to examine participants preference choices in the 2AFC. Results showed that participants chose the curved drawings significantly above chance level (M = .61), t (48) = 5.54, $p < .001$, 95% CI [.57–.65], $d = .79$ (Fig. 4A). Next, we modelled the curved choices as the variable to be predicted. The model included Category (computer-made vs. hand-made), Shading (shaded vs. not shaded), Position (frontal vs. $\frac{3}{4}$ view), and the interaction between these factors as fixed effects. The best model included random intercepts within participant and stimulus. Influential cases analysis revealed no influential values exceeding the recommended cut-off point, which was .089. Results revealed no significant effect either for Category, $\beta = -1.38$, SE = .76, Z = −1.81, $p = .070$, 95% CI [−2.9–.11], Shading, $\beta = .02$, SE = .53, Z = .04, $p = .96$, 95% CI [−1.02–1.06], or Position, $\beta = -.74$, SE = .53, Z = −1.4, $p = .16$, 95% CI [−1.8–.30]. Moreover, there was no significant interaction between Category × Shading, $\beta = .27$, SE = .94, Z = .29, $p = .77$, 95% CI [−1.57–2.1], Category ×Position, $\beta = .90$, SE = .71, $Z = 1.26$, $p = .21$, 95% CI [−.50, 2.3], or Shading x Position, $\beta = .75$, SE = .72, $Z = 1.04$, $p = .30$, 95% CI [−.66, 2.15]. These results indicated that the choice of the curved drawing does not depend on the category of the drawing, whether or not it is shaded, and whether it is in frontal or $\frac{3}{4}$ view.

On the other hand, the familiarity selection task showed that the curved shapes were selected as the most familiar in a proportion of .45, the sharp-angled shapes were selected as the most familiar in a proportion of .21, and both shapes were selected as equally familiar in a proportion of .34. We modelled whether familiarity selection predicted preference in the 2AFC task. The model included curved choices as the variable to be predicted.

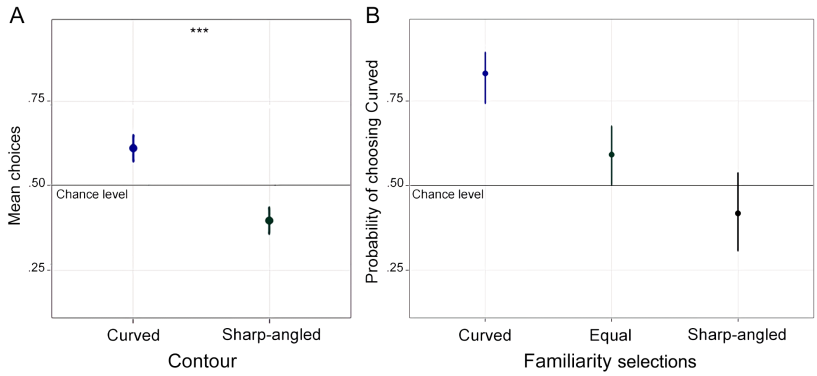

Figure 4 Preference choices and familiarity selections of Experiment 2. (A) Mean choices of the curved and sharp-angled drawings in the 2AFC task. (B) Probability of choosing the curved drawings in the 2AFC task within the three alternative responses of the Familiarity selection task. Familiarity selections for the curved shapes and both shapes selected as equally familiar predicted a higher probability of choosing the curved drawings in the 2AFC. Error bars represent 95% CI ($^{***}p < .001$).

Full-size DOI: 10.7717/peerj.11772/fig-4

Familiarity (curved, equally, sharp-angled) and Lateralization (left vs. right) were included as categorical fixed effects. The best model included random slopes within participant. Influential cases analysis revealed no extreme values exceeding the recommended cut-off point, which was .087. Results showed a main effect when we compared the pairs in which the curved shape was the most familiar and the pairs in which the sharp-angled shape was the most familiar, $\beta = 1.90$, SE = .35, $Z = 5.5$, $p < .001$, 95% CI [1.22–2.6]. Post-hoc tests revealed that curved preference was higher when the curved shapes were selected as the most familiar (M = .83, 95% CI [.74–.89]) than when the sharp-angled shapes were selected as the most familiar (M = .42, 95% CI [.31–.53]), OR (Odds Ratio) = 6.72, 95% CI [4.1–13.2]. That is, when participants selected the curved shapes as the most familiar ones, they also mostly preferred the curved drawings over the sharp-angled ones in the 2AFC task, but this was not the case when participants selected the sharp-angled shapes as the most familiar ones. Similarly, there was a main effect when we considered the curved shapes selected as the most familiar ones and both shapes selected as equally familiar, $\beta = 1.22$, SE = .25, $Z = 4.96$, $p < .001$, 95% CI [.74–1.71]. Curved preference choices were higher when the curved shapes were selected as the most familiar ones than when both shapes were selected as equally familiar (M = .59, 95% CI [.50–.67]), OR = 3.4, 95% CI [2.1–5.5]. Lastly, there was a main effect when we considered both shapes selected as equally familiar and the sharp-angled shapes selected as the most familiar ones, $\beta = .68$, SE = .23, $Z = 2.9$, $p = .0035$, 95% CI [.22–1.14]. Post-hoc comparisons showed that curved preference was higher when participants selected both shapes as equally familiar than when they selected the sharp-angled shapes as the most familiar ones, OR = 1.98, 95% CI [1.25–3.12] (Fig. 4B). These results suggest that participants preferred the drawings they chose as more familiar. They also support the findings from Experiment 1, suggesting that shape familiarity modulates preference for curvature between tasks.

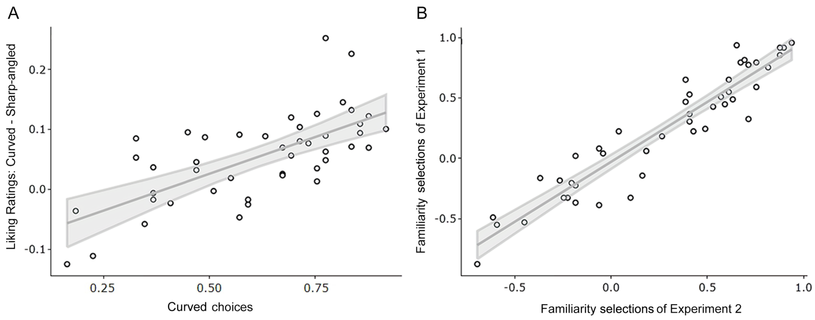

Figure 5 Scatterplots showing the relation between the data from experiments 1 and 2. (A) Relation between the liking ratings (Experiment 1) and the curved choices in the 2AFC (Experiment 2). (B) Relation between the familiarity selections data of Experiment 1 and 2. Each point represents a pair of drawings. All p's $< .001$.

Full-size DOI: 10.7717/peerj.11772/fig-5

Regarding the individual measures, we modelled whether they modulated contour preference choices. The model included Art interest, Art knowledge, Openness to experience, Unconventionality facet, and TIntS subscales (HA, HB, I and A) as predictors. These predictors were centred on the grand mean. The best model included random slopes within participant and stimulus. Influential cases analysis revealed four influential values exceeding the recommended cut-off point, which was .10. Thus, these participants were excluded from the analysis. Results showed that participants who scored higher in the HB subscale showed a significantly higher preference for curved drawings, $\beta = .13$, SE = .04, $Z = 3.5$, $p < .001$, 95% CI [.06–.20]. Those who scored higher in the A subscale also showed a significantly higher preference for curved drawings, $\beta = .052$, SE = .016, $Z = 3.3$, $p < .001$, 95% CI [.02–.08]. In contrast, participants who scored higher in the Unconventionality facet showed significant lower preference for curved drawings, $\beta = -.09$, SE = .04, Z = -2.2, $p = .028$, 95% CI [$-.17$ to $-.01$]. The other effects were nonsignificant. All effects are included in *Table S2* as supplementary material.

Correlations between experiments

We analysed the correlation between the data from the two experiments to determine the consistency of responses to the same drawings from different participants. First, we performed a correlation analysis based on drawings between liking ratings in Experiment 1 and preference choices in Experiment 2. From Experiment 1, we calculated the difference between the liking for the curved drawing and the sharp-angled drawing of each pair. We correlated these values with the choice mean (between 0 a 1) for each pair of drawings from the 2AFC task in Experiment 2. Subsequently, the bias-corrected and accelerated CI was calculated using the bootstrap resampling method with 1499 samples suggested for a test at the 0.05 and 0.01 level (*Davidson & MacKinnon, 2000*). Results revealed a significant positive correlation between the liking ratings and curved preference choices, $r_s(45) = .66$, $p < .001$, 95% CI [.46–.80]. This result supported a positive relationship of preference for drawings between tasks (Fig. 5A).

Second, we compared the familiarity responses of participants in the two experiments. We obtained a familiarity value for each pair of stimuli regarding the three-alternative responses from the familiarity selection tasks. That is, we grouped the trials where participants selected the curved shape as the most familiar (+1) sharp-angled shape as the most familiar (−1) and both shapes as equally familiar (0) to obtain a familiarity value between −1 and 1 for each pair of stimuli. Then, we correlated these values between both familiarity selection tasks and calculated CI as in the first correlation. Results showed a strong positive association of familiarity judgements between the two experiments, $r_s(45) = .92$, $p < .001$, 95% CI [.88, .94]. These results supported that familiarity with the shape of the objects was consistent across different participants (Fig. 5B).

Discussion

Experiment 2 showed that participants preferred the curved drawings over the sharp-angled ones. This result supported our main hypothesis about the curvature effect (*Corradi & Munar, 2020*). Therefore, together with the results from Experiment 1, we suggest a consistent preference for the curved drawings of common-use objects between tasks.

We also found that familiarity for the curved stimuli predicted a higher preference for curvature in the 2AFC task than familiarity for the sharp-angled stimuli and the stimuli selected as equally familiar. That is, when the curved shapes were selected as the most familiar ones, there was a higher preference for curvature. Similarly, there was preference for curvature when participants selected both shapes as equally familiar. In contrast, we did not find preference for angularity or for curvature when participants selected the sharp-angled shapes as the most familiar ones. These results support the influence of familiarity on preference. However, they also showed that familiarity is not the only factor determining preference for drawings of common-use objects.

On the other hand, some individual measures influenced preference choices. Specifically, participants who scored higher in the HB and A subscales of the TIntS showed a higher preference for the curved drawings. In contrast, those who scored higher in the Unconventionality facet showed less preference for the curved drawings. These results suggest that the 2AFC task is a more sensitive procedure to find the potential influence of individual differences in preference for curvature than the liking rating task. Conversely, the results also suggest an uncertain influence of some individual measures (e.g., art expertise or openness to experience) on preference for curvature (*Corradi et al., 2019b*).

Finally, the correlation analysis between the data from the two experiments showed a similar pattern of preference for the pair of drawings. On the other hand, the perception of familiarity with the shape of the objects and their representational content was highly consistent using two different groups of participants.

GENERAL DISCUSSION

We examined preference for curvature and its relationship with familiarity using drawings of common-use objects in two experiments. Experiment 1 consisted of a liking rating task, a familiarity selection task, and a set of individual measures. Experiment 2 used the same stimuli and different participants, and consisted of a 2AFC task simulating approach/avoidance responses, and the same familiarity selection task and individual measures of Experiment 1.

In Experiment 1, we found higher liking ratings for the curved than the sharp-angled drawings. Similarly, in Experiment 2, participants preferred the curved drawings over chance level in the 2AFC task. These findings support the curvature effect using drawings of common-use objects (*Corradi & Munar, 2020*). They also support the preference for curvature as a consistent effect between different experimental designs (*Palumbo & Bertamini, 2016*; *Chuquichambi et al., 2021*). Conversely, our findings diverge from those of some previous studies using images of real-objects. *Munar et al. (2015)* did not find preference for curved objects in a 2AFC task in the until-response condition. Similarly, using the same task and stimuli than *Munar et al. (2015)*, *Corradi et al. (2018)* found that the effect of preference for curvature decreased as the presentation time increased. They suggested a higher influence of the meaning and content-related information of stimuli as the presentation time increased. In this regard, they found that the effect of preference for curvature was stronger when presenting abstract patterns in longer presentation time compared to brief presentations. With Japanese participants, *Maezawa, Tanda & Kawahara (2020)* did not find a preference for curvature using similar stimuli as *Corradi et al. (2018)* and like/dislike and rating scale tasks. A possible explanation of these divergences may be related to the interaction between the meaningful and representational content of the object, familiarity with its shape, and the artistic view of the drawings because of their design and artistic nature (*Schroll, Schnurr & Grewal, 2018*).

The curved drawings were mostly preferred when the curved shape was selected as the most familiar or when the two shapes were selected as equally familiar, but not when the sharp-angled shape was selected as the most familiar. Further, in both experiments, preference for the curved drawings was higher when the curved shape was selected as the most familiar than when both shapes were selected as equally familiar. These findings support familiarity as a strong predictor of preference (*Reber, Winkielman & Schwarz, 1998*; *Reber, Schwarz & Winkielman, 2004*; *Verhaeghen, 2018*; *Chmiel & Schubert, 2019*). However, they also suggest that familiarity is not the only factor determining preference for curvature because participants still preferred the curved drawings over the sharp-angled ones when the two shapes of the objects were selected as equally familiar. Moreover, there was no preference for the sharp-angled drawings when the sharp-angled shape was selected as the most familiar. In addition, these findings might support curvature as one of the diverse fluency-enhancing variables that explains the relationship between prototypicality and attractiveness (*Winkielman et al., 2006*).

Our results on the relationship between preference for curvature and familiarity might also be connected to the predominant role of curvature on shape's perception (*Pasupathy & Connor, 2002*). Our visual system might integrate curved features more efficiently because they tend to match the statistic regularities of the natural environment (*Sigman et al., 2001*; *Bertamini, Palumbo & Redies, 2019*; *Stanischewski et al., 2020*). Relatedly, our results might also be explained because of a higher frequency of curved contours in natural scenes (*Ruta et al., 2019*). In a recent study, *Yue, Robert & Ungerleider (2020)* found a specialized cortical network for curvature processing in humans. They suggested the interaction between preference for curvilinearity with central-peripheral processing biases as an important organizing principle for temporal cortex topography. Interestingly, they also found a possible link between curvature-preferring areas and face-selective areas. This study also dealt with curvature as a metric property. However, *Amir, Biederman & Hayworth (2011)*; *Amir, Biederman & Hayworth (2012)* showed greater sensitivity to the non-accidental property related to the difference between curved and straight contours than to the metric property of curvature. Our brain might represent the non-accidental property in a different way than the metric property of curvature. Altogether, these studies and the interaction between the representational nature of the objects and the artistic characteristics of the drawings within the same stimuli may explain our results of the role of familiarity in preference for curvature.

However, the current research line on preference for curvature leaves open the role that could play the phenomenology of how space appears to the perceiver. In particular, some artists use a curvilinear perspective, instead of a linear perspective because it is closer to the viewer's experience that straight lines in nature can be perceived as curved ones(*Pepperell, 2012*; *Pepperell & Haertel, 2014*). On the other hand, a curved line can even appear as a straight line when viewed head-on, or circles in the peripheral visual field can appear polygonal in shape (*Baldwin et al., 2016*). Further research is needed to address this issue.

Besides the role of object characteristics, previous studies reported that individual measures also can modulate preference for curvature (e.g., *Cotter et al., 2017*; *Silvia & Barona, 2009*). In Experiment 1, we only found that higher scores in the HB subscale predicted higher preference for all the drawings. However, we found some individual differences in Experiment 2, which leads us to suggest that the 2AFC task is more sensitive to finding them than the liking rating task. Specifically, participants with higher scores in the HB and A subscales showed a higher preference for curvature. The influence of the HB type of intuition in preference for curvature might be explained because curved contours facilitate fluent global processing of the stimuli (*Reber, Schwarz & Winkielman, 2004*; *Gómez-Puerto, Munar & Nadal, 2016*). On the other hand, the relationship between the A subscale and the preference for curvature could result from associations with positive valence underlying preference for curvature (*Palumbo, Ruta & Bertamini, 2015*).

Our results also showed that higher scores in the Unconventionality facet predicted less preference for the curved drawings in Experiment 2. This might be related to the idea that the sharp-angled shapes are perceived as more avant-garde (*Ruta et al., 2021*) and unconventional people tend to show a higher preference for innovative designs. Interestingly, *Cotter et al. (2017)* found that higher unconventionality scores predicted more preference for curvature using irregular polygons. However, they found no effect using arrays of circles and hexagons. Using the same arrays of circles and hexagons, *Silvia & Barona (2009)* found preference for curvature in participants without art training –probably more conventional people–but there was no effect with art-trained participants –probably more unconventional people. Artists may show more unconventional thinking and express it in their art because this may make their work more impactful than more conventional artistic styles (*Stamkou, Van Kleef & Homan, 2018*). Conversely, these authors found preference for curvature in art-trained participants but not in participants without training when they rated complex polygons. Considering these studies, preference for curvature might be higher in art-trained and unconventional participants when the stimuli are more complex. However, we found no influence on preference for curvature from the Art interest and Art knowledge Scales, as in Corradi et al. (2019b). These authors reported that the influence of art interest and art knowledge on aesthetic sensitivity was inconsistent. Altogether, our findings suggest that the influence of individual differences in preference for curvature might depend on the kind of stimuli.

On the other hand, we found significant positive correlations between the results of both experiments. The difference in liking ratings between curved and sharp-angled drawings (Experiment 1), and the preference choices for the curved drawings (Experiment 2) showed a similar pattern of preference. This finding supports a consistent and predictable preference for drawings as representational images (Vessel & Rubin, 2010; Schepman, Rodway & Pullen, 2015; Schepman, Rodway & Pullen, 2015). Although drawings also have art-related characteristics, our results indicate that these characteristics did not weaken the preference consistency between participants. On the other hand, the highly positive correlation between the familiarity selection tasks endorse a robust concept of familiarity of object drawings regardless of the participants.

A possible limitation of this study is that we used a subjective measure of familiarity. The familiarity values came from the direct response of the shape participants considered familiar for the objects. Previous studies used measures based on the exposure time or the number of presentations of the stimulus, that is, a process of familiarization (e.g., Berlyne, 1970; Berlyne, 1971; Tinio & Leder, 2009). However, Sluckin, Hargreaves & Colman (1982) argued that subjective measures of familiarity, compared to objective measures, might be more suitable because of a larger variance within each individual and stimulus. Moreover, the drawings involved content-related information. Repeated exposure would likely lead to habituation and, as a consequence, preference could decline (Biederman & Vessel, 2006). Using subjective measures, participants only need a single presentation of the stimulus to evaluate its representational content as more or less familiar. Moreover, the subjective familiarity of the shape of an object might be modulated by participant's individual differences. Thus, future studies could assess the role of individual differences on shape familiarity in order to complement our findings of the relationship between these variables with preference for curvature.

CONCLUSIONS

In summary, we found preference for curvature using drawings of common-use objects in two experiments. The curved shapes of the objects were also selected as the most familiar ones in both experiments. When the curved shapes were selected as the most familiar, and when both shapes were selected as equally familiar, participants showed preference for the curved drawings. However, when the sharp-angled shapes were selected as the most familiar, participants did not show preference for curvature or for angularity. These findings support the idea that shape familiarity modulates preference for drawings of common-use objects. However, they also indicate that the influence of familiarity is not the only factor explaining the preference for curved drawings. The influence of individual differences in preference for the drawings suggested that the kind of stimuli and the experimental task may predict divergencies across studies and measures. Correlation analyses between experiments also supported a consistent relationship of preference between tasks, and a coherent concept of familiarity of the same pair of object drawings. Altogether, our findings endorse the curvature effect using drawings of common-use objects and familiarity as an important predictor of preference.

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ADDITIONAL INFORMATION AND DECLARATIONS

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Competing Interests

The authors declare there are no competing interests.

Author Contributions

- Erick G. Chuquichambi conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the paper, and approved the final draft.
- Letizia Palumbo and Carlos Rey conceived and designed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the paper, and approved the final draft.
- Enric Munar conceived and designed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the paper, and approved the final draft.

Human Ethics

The following information was supplied relating to ethical approvals (i.e., approving body and any reference numbers):

The study received ethical approval from the Committee for Ethics in Research (CER) of the UIB (Ref: IB 3828/19 PI).

Data Availability

The following information was supplied regarding data availability:

The datasets generated in the experiments and the dataset used for correlation analyses are available in the Supplemental Files.

The raw code and raw datasets are available on the Open Science Framework: Chuquichambi, Erick G, Letizia Palumbo, Enric Munar, and Carlos Rey. 2021. "Shape Familiarity Modulates Preference for Curvature in Drawings of Common-Use Objects." OSF. DOI: 10.17605/OSF.IO/XGJ690.

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3.5. Humans prefer to see and imagine drawing curved objects

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Erick G. Chuquichambi[1], Daniela Sarria[1], Guido B. Corradi[1,2], and Enric Munar[1]

Abstract

Lines contribute to the visual experience of drawings. People show a higher preference for curved than sharp angled lines. We studied preference for curvature using drawings of commonly-used objects drawn by design students. We also investigated the relationship of that preference with drawing preference. Experiments 1 and 2 revealed preference for the curved drawings in the laboratory and web-based contexts, respectively. Experiment 3 showed that the curved drawings were also preferred to draw than the sharp-angled ones. However, this effect only appeared when the drawings were made by hand, but not when they were made by computer. We found a moderate positive correlation between liking and drawing preference. This relationship was mainly explained by the hand-made drawings. Sex, art experience and openness to experience did not influence preference for curvature. Altogether, our findings support the curvature effect and the hypothesis that people prefer to draw what they like to see.

Keywords

curvature, commonly-used objects, preference, drawing preference, hand-made drawings

[1]Human Evolution and Cognition Group (EvoCog), University of the Balearic Islands, Palma de Mallorca, Spain
[2]Department of Psychology, Faculty of Education and Health, University Camilo José Cela, Madrid, Spain

Corresponding Author:
Erick G. Chuquichambi, Faculty of Psychology, University of the Balearic Islands, Ctra. Valldemossa km 7'5, 07122 Palma de Mallorca, Spain.
Email: erik.chuquichambi@uib.es

A drawing is a kind of image that is frequently used in people's day-to-day lives. They are usually created to communicate and to clarify information. Although we can describe a drawing in different ways, we initially define it as the resulting product when a person uses a moving point, usually a mark-making point, with the aim of creating a pattern of marks or lines on a surface. According to Dinham (1989), line is the first and fundamental drawing mark and during the Renaissance it was regarded as the "heart of art" because it was considered a superior analytical device and means for giving form to ideas and perceptions. The inherent qualities of lines contribute to the visual experience of the drawings and drawing is considered a fundamental, core subject in the art education and academic curriculum (Dinham, 1989; Houghton, 2016).

In addition, it has been proved extensively that people have greater preference for curved than for sharp-angled lines and contours in the field of Empirical Aesthetics (Bertamini & Palumbo, 2015; Corradi & Munar, 2020; Gómez-Puerto, Munar, & Nadal, 2016). Despite the beauty of smooth curvature being seen in many examples of visual art (Bertamini & Palumbo, 2015), preference for curvature has been scarcely demonstrated experimentally in the field of art (Ruta et al., 2021).

A few recent studies have shown the effect of curvature in drawings (Bertamini & Sinico, 2021; Chuquichambi, Palumbo, Rey, & Munar, 2021). Bertamini and Sinico (2021) used images drawn by design students. Each student drew curved and sharp-angled versions of seven different objects. In the experimental task, naïve participants found the curved versions more beautiful, darker, more complex, heavier, older, safer, and more asymmetrical than the sharp-angled versions. This study also showed that the drawings judged as more beautiful were also those perceived as more modern, light (brightness), light (weight), safe, and symmetrical. Chuquichambi et al. (2021) also reported a consistent preference for curvature using a subset of these object drawings in two different tasks. Importantly, these authors showed that familiarity with the shape of the objects and individual differences affected preference for these drawings. They found that participants preferred the curved drawing more than the sharp-angled drawing both when the curved version was selected as the most familiar and when the two versions were selected as equally familiar. In contrast, none of the individual differences influenced preference for the drawings in a consistent manner. Altogether, these findings have contributed the aim of the present study on investigating the relationship between preference and drawing preference using commonly-used objects.

Based on the idea that cognitive processes in the creation and the reception of art have some similarities (Tinio, 2013), Williams, McSorley, and McCloy (2018) demonstrated that there is relationship between visual preference and drawing preference for production in artists and nonartists. They concluded that the more pleasing a drawing was, the greater the preference to draw it, regardless of expertize in art. The stimuli they used were abstract geometric shapes. They indicated that a useful next step would be to replicate the study with more realistic stimuli.

The hypothesis from Tinio (2013) and Williams et al. (2018) suggests that people prefer to draw what they like. With this hypothesis in mind, we investigate preference for curvature and drawing preference using a selection of images from Bertamini and Sinico (2021), and creating some additional images in order to balance the number of images across two variables, type of contour (curved/sharp-angled) and category (hand-made and computer-made). Schroll, Schnurr, and Grewal (2018) showed that handwritten typefaces provide more positive effects than machine-written typefaces. It is reasonable to think that this effect can be transferred to hand-made and computer-made drawings. For this reason, we also balanced and analyzed hand-made and computer-made drawings in order to determine their influence on visual and drawing preference in the curvature effect.

Some studies have shown that sex (McElroy, 1954), art expertize (Silvia & Barona, 2009; Vartanian et al., 2017), and openness to experience (Cotter, Silvia, Bertamini, Palumbo, & Vartanian, 2017) could influence preference for curvature. However, other studies have not found this relationship (Corradi et al., 2019a), and highlighted variability between participants and stimuli to explain inconsistent findings across studies (Corradi, Chuquichambi, Barrada, Clemente, & Nadal, 2019b). Furthermore, expertize might also modulate drawing production. When viewing art, artists may show higher interest than non-artists in the creative process of the artwork (Tinio, 2013). For these reasons, we included sex and measures of art experience and openness to experience in the experimental study.

Purpose of the Present Study

In this study, we examined preference for curvature using hand-made and computer-made drawings of commonly-used objects and the relationship of that preference with drawing preference. We used pairs of drawings designed by quasi-expert students in design as described by Bertamini and Sinico (2021). Each pair of drawings represented curved and sharp-angled versions of the same object. Experiment 1 consisted of a liking rating task carried out in the laboratory. Experiment 2 consisted of a web-based replication of Experiment 1. Lastly, Experiment 3 consisted of a web-based drawing preference choice task. This final task asked participants to choose which of each pair of drawings they would prefer to draw and to indicate the strength of this preference on a scale (Park, Shimojo, & Shimojo, 2010; Williams et al., 2018). In Experiments 1 and 2, we expected that participants would prefer the curved drawings as shown by previous studies (Bertamini & Sinico, 2021; Chuquichambi et al., 2021). In Experiment 3, we expected that participants would prefer to draw the curved stimuli because of the relationship between aesthetic and drawing preference reported by Williams et al. (2018). We also expected liking scores (Experiments 1 and 2) and drawing preference (Experiment 3) to be related. In the three experiments, we included an art experience questionnaire (Corradi et al., 2019b), and the openness to experience scale from the NEO-FFI (McCrae & Costa, 2004). According to previous studies, these variables might modulate preference for curvature (e.g., Cotter et al., 2017).

Moreover, expertize might also modulate drawing preference (Williams et al., 2018). Therefore, we explored whether these individual differences modulated aesthetic and drawing preference using curved and sharp-angled drawings of commonly-used objects.

Experiment 1

Method

Participants. Thirty adult students (18 female, $M_{\text{age}} = 23.7$, $SD_{\text{age}} = 4.1$) at the University of the Balearic Islands (UIB) volunteered to participate in the experiment. They reported normal or corrected to normal vision and provided written informed consent before the experiment. The experiment received ethical approval from the Committee for Ethics in Research (CER) of the Balearic Islands.

Stimuli and materials. Forty-eight drawings of commonly-used objects were used as stimuli. Twenty-eight drawings designed by quasi-expert students in Design were selected from the IUAV image database (https://osf.io/cx62j/) (Bertamini & Sinico, 2021). Half of the selected drawings were curved and the other half were sharp-angled. The selection was made with consideration that the curved and the sharp-angled versions did not significantly differ in size (in bytes, $W = 100$, $p = .68$), ratio of compression (jpeg ratio, $t = .43$, $p = .67$), or perceived lightness ($t = -.77$, $p = .45$) according to the database. The drawings also differed in variables such as category (computer-made vs. hand-made) and shading (shaded vs. non-shaded). One of the authors (DS) designed the other twenty drawings using Adobe Illustrator (Adobe Inc., 2019) in order to balance the number of pairs of drawings in the same category and the numbers of shaded and non-shaded drawings. The final set of drawings consisted of twenty-four pairs. Each pair represented a curved and a sharp-angled version of the same object. Half of the pair of drawings were hand-made and half were computer-made. Half of the curved and sharp-angled drawings were shaded and half were non-shaded. Each pair of drawings was made the same size and framed on an outline of 600 pixels height, 600 pixels width (Figure 1).

The liking task recorded participants' ratings for each drawing using a horizontal sliding bar from 0 to 100 as in Chuquichambi et al. (2021). The ends of the bar had the labels "I don't like it" (0) on one side, and "I like it very much" (100) on the other side. Each stimulus was presented on the center of the screen until participants responded using the mouse. There were 8 practice trials using additional stimuli, and 48 experimental trials corresponding to the 24 stimuli pairs. The trial sequence was randomized. Participants subsequently completed two questionnaires. The first questionnaire was an art experience scale adapted from Chatterjee, Widick, Sternschein, Smith, and Bromberger (2010). The second questionnaire was the openness to experience scale from the NEO FFI (McCrae & Costa, 2004).

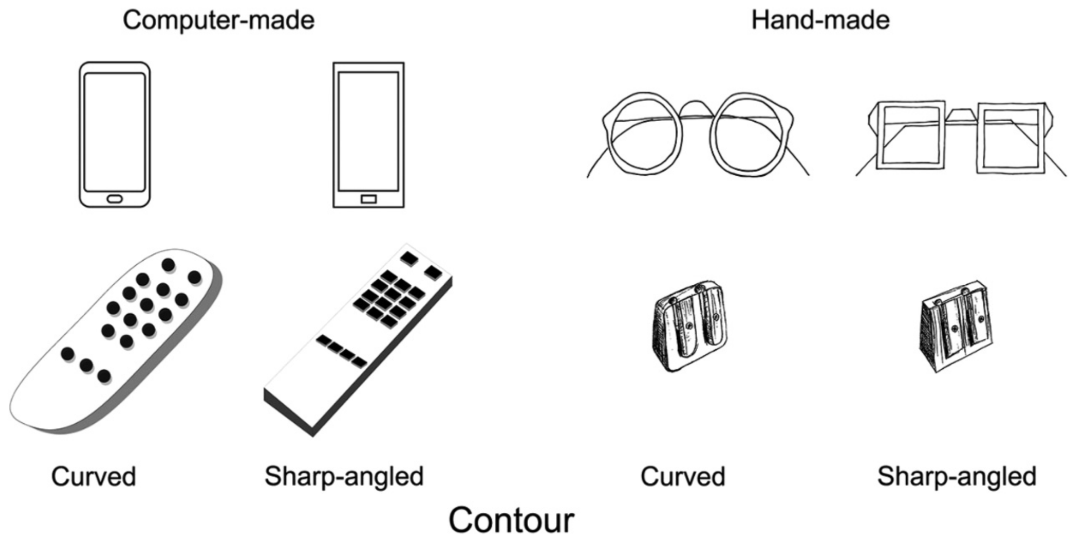

Figure 1. Examples of the drawings of commonly-used objects used in the study, from the Bertamini and Sinico (2021) image database.

The task and questionnaires were presented with OpenSesame (3.3) software (Mathôt, Schreij, & Theeuwes, 2012). They were implemented using computers equipped with Intel i5 processors and 21-inch screens set at 1,920 × 1,080 pixels.

Procedure. Participants took part in the experiment in the UIB psychology laboratory. First, they were welcomed and asked to give their written informed consent. Following that, they entered isolated cubicles and used individual computers each with the same software and lighting conditions. In the liking task, instructions asked participants to rate how much they liked each drawing, displayed in the center of the computer screen, using the mouse on the horizontal sliding bar. Subsequently, the participants completed the questionnaires. The experimental session lasted about 10 min. Finally, the participants were debriefed and thanked (Table 1).

Data analysis. We carried out analyzes within the R environment for statistical computing (R Core Team, 2018). Participants' responses in the liking task and questionnaires were analyzed by means of linear mixed effects models (Hox, 2010; Snijders & Bosker, 2012). We used the *lme4* package (Bates, Mächler, Bolker, & Walker, 2015) to fit the models and the *afex* package (Singmann, Bolker, Westfall, & Aust, 2016) to produce the inferential statistics and *p* values. The *lsmeans* package was used to obtain predicted means for the fixed effects (Lenth, 2016). The models included participant and stimulus as random effects. Models were selected comparing their fit indices and following the guidelines from Barr, Levy, Scheepers, and Tily (2013) and Brauer and Curtin (2018) in order to select the maximal random effect structure justified by the experimental design. Lastly, we performed an analysis of

Table 1. Descriptive Statistics for the Individual Difference Measures in the Three Experiments.

Measures	Mean	Median	SD	Min–Max
Experiment 1 (n = 30)				
Art Experience	15.2	13.5	9.55	2–38
NEO: Openness to Experience	49.2	49	4.83	36–56
Experiment 2 (n = 59)				
Art Experience	14.2	13	8.31	3–38
NEO: Openness to Experience	45.6	46	6.85	28–59
Experiment 3 (n = 67)				
Art Experience	17.03	16.5	8.7	3–37
NEO: Openness to Experience	37.4	38	3.19	30–45

Note. Score ranges: Art Experience (0–48), Openness to Experience (12–60).

influential cases based on Cook's distance in each model to evaluate how the removal of extreme case participants impacted the results.

Results

We used two different models with the aim to tackle the two main objectives. On the one hand, we analyzed the possible curvature effect and the influence from the two characteristics of the stimuli, plus the factor sex as a possible moderator of these two characteristics. On the other hand, we analyzed the possible influence of art experience and openness to experience on the curvature effect and the other characteristics of the stimuli.

The first model predicted liking ratings based on Contour (curved vs. sharp-angled), Category (computer-made vs. hand-made), Shading (shaded vs. non-shaded), Sex, and the interaction between these effects as predictors. We included the two-way interactions of Contour with the other three factors. The model with the best fit indices included random slopes for Contour within participant and stimulus. Influential case analysis revealed two extreme cases with values above the recommended cut-off point, which was.16. Therefore, these participants were excluded from the analysis.

Participants significantly liked the curved drawings ($M = 53$, *95% CI* [48, 58.3]) more than the sharp-angled drawings ($M = 44$, *95% CI* [38, 50]), $\beta = 4.51$, $SE = 1.54$, $t(28.7) = 2.92$, $p = .0067$, *95% CI* [1.48, 7.54] (Figure 2(a)). They also liked the shaded drawings ($M = 55$, *95% CI* [49, 60.8]) more than the non-shaded drawings ($M = 42.2$, *95% CI* [36.3, 48]), $\beta = 6.4$, $SE = 1.74$, $t(21.05) = 3.66$, $p = .0014$, *95% CI* [2.97, 9.81]. In contrast, liking ratings did not differ significantly between the hand-made ($M = 47.6$, *95% CI* [41.7, 53.5]) and computer-made drawings ($M = 49.5$, *95% CI* [43.6, 55.4]), $\beta = -.96$, $SE = 1.73$, $t(21.88) = -.55$, $p = .58$, *95% CI* [−4.34, 2.43], nor between men ($M = 50.8$, *95% CI* [44.3, 57.1]) and women ($M = 46.4$,

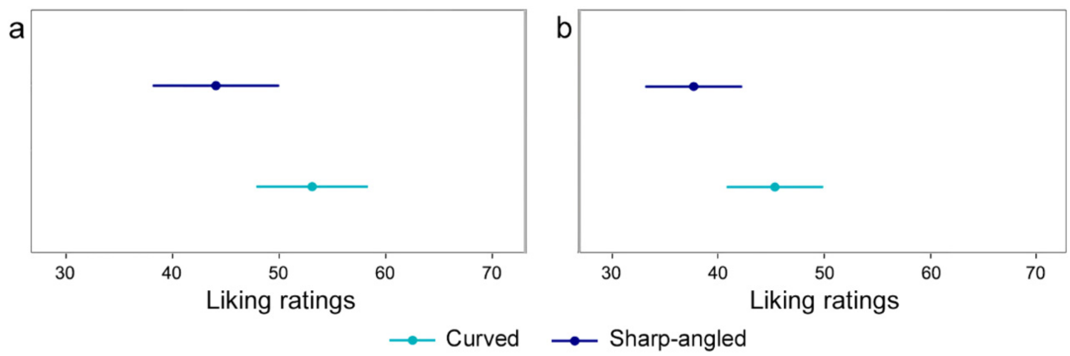

Figure 2. Mean liking ratings in experiment 1 (a) and experiment 2 (b). Error bars represent 95% CI around the means.

95% CI [41.4, 51.3]), $\beta = -2.18$, $SE = 1.6$, $t(26) = -1.36$, $p = .18$, *95% CI* [−5.32, 0.96]. However, the interaction between Category and Sex was significant, $\beta = 1.96$, $SE = .69$, $t(1{,}241) = 2.84$, $p = .0046$, *95% CI* [.61, 3.32]. Although the men in the study indicated greater preference for computer-made drawings than the women, $\beta = 8.28$, $SE = 3.6$, $t(36.5) = 2.3$, $p = .027$, there was no significant difference between men and women in the liking for hand-made drawings, $\beta = .43$, $SE = 3.6$, $t(36.5) = .12$, $p = .90$ (Figure 3(a)).

The second model predicted liking ratings based on the interaction of Contour, Category, and Shading with Art Experience and Openness to Experience (i.e., six two-way interactions, 3×2). The individual differences measures were included in the model as continuous predictors, and participants' scores were centered on their grand mean before analysis. The model included random slopes within participant and stimulus. Influential case analysis revealed five extreme case values exceeding the recommended cut-off point, which was.167. Therefore, these participants were excluded from the analysis. Results showed a significant interaction between Contour and Openness to Experience, $\beta = .75$, $SE = .27$, $t(32.4) = 2.73$, $p = .010$, *95% CI* [.21, 1.28]. Participants with higher scores in Openness to Experience liked the curved drawings more and disliked the sharp-angled ones more. There was also a significant interaction between Category and Art Experience, $\beta = .33$, $SE = .096$, $t(37.9) = 3.43$, $p = .0015$, *95% CI* [.14, .52]. Participants with higher scores in Art Experience liked the hand-made drawings more and disliked the computer-made drawings more. All other effects and interactions were non-significant.

Discussion

Participants liked the curved drawings more than the sharp-angled drawings. This result supports our hypothesis and previous literature using stimuli from the same image database (Bertamini & Sinico, 2021; Chuquichambi et al., 2021; Sinico, Bertamini, & Soranzo, 2021). In a broader sense, this finding is also in line with those from previous studies about the curvature effect using representational

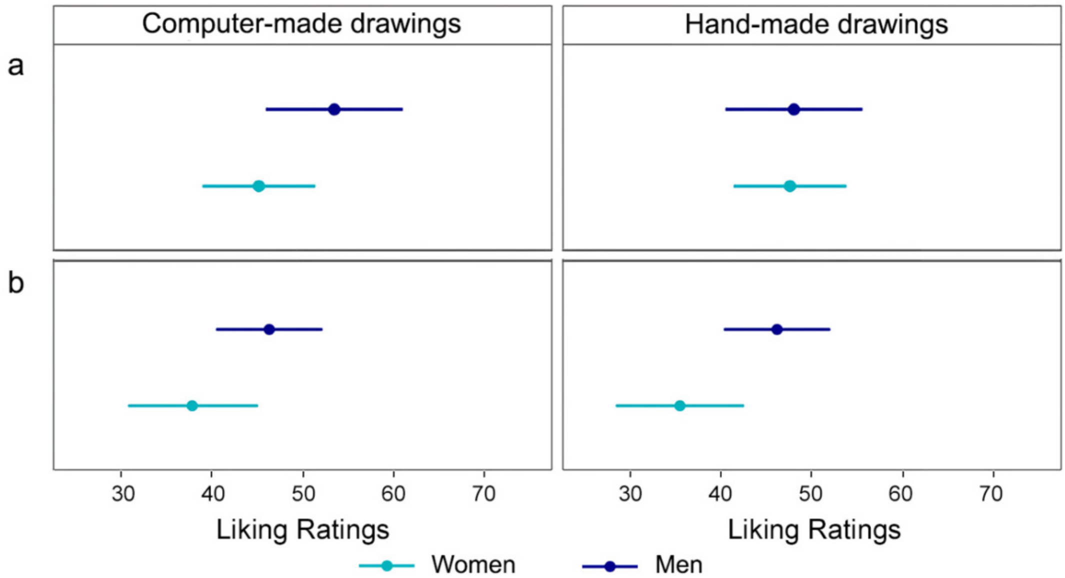

Figure 3. Category and Sex interaction in experiment 1 (a) and experiment 2 (b). Left and right plots show computer-made and hand-made drawings, respectively. Error bars represent 95% CI around the means.

(Madani, 2007), and non-representational drawings (e.g., Corradi et al., 2019a). Participants also liked the shaded drawings more than the non-shaded drawings.

Results related to individual differences showed that the men liked the computer-made drawings more than the women, but this was not the case with hand-made drawings. In addition, higher scores in openness to experience predicted higher preference for the curved drawings, and lower preference for the sharp-angled drawings. This finding diverges from the non-significant effect of openness to experience reported by Chuquichambi et al. (2021). In contrast, it supports the effect of openness to experience reported by Cotter et al. (2017) with curved irregular polygons. Finally, higher art experience predicted higher preference for the hand-made drawings, and lower preference for the computer-made drawings.

Despite the results seeming to be quite consistent with the literature (e.g., Bertamini and Sinico, 2021), previous studies have also indicated that some findings in the field of Empirical Aesthetics might be context-dependent (Brieber, Nadal, Leder, & Rosenberg, 2014; Hůla & Flegr, 2016), and that we should move beyond the student population (Palumbo et al., 2020). For this reason, we conducted a web-based replication of the same experiment outside of the lab environment.

Experiment 2

Experiment 2 was an online replication of Experiment 1 using the opensource Psytoolkit software (Stoet, 2017). Based on the results of Experiment 1, we expected a higher preference for the curved drawings than for the sharp-angled drawings. Furthermore, we expected to confirm the other results found in the Experiment 1.

Method

Participants. Fifty-nine adult participants (24 female, $M_{age} = 34$, $SD_{age} = 15$) volunteered to participate in the experiment. They were recruited through an advertisement sent by email to students forums, and via social networking (i.e., Facebook and Twitter). They reported normal or corrected to normal vision and provided written informed consent before the experiment. The experiment was conducted following the same ethical and experimental considerations as Experiment 1.

Materials and procedure. We used the same 48 drawings and the same liking rating task as in Experiment 1, but carried out on the internet. This task presented each drawing individually with a horizontal sliding bar from 0 to 100. Subsequently, participants completed the same two questionnaires as in Experiment 1.

In order to take part in the experiment, participants had to have a computer screen of at least 1,280 × 720 pixels resolution. First, they indicated their age, sex, and highest academic qualification. Then, they received the same instructions as in Experiment 1 before the liking task and questionnaires. The experiment lasted about 10 min. Finally, participants were debriefed and thanked.

Data analysis. Analyzes were carried out using linear mixed effects models, following the same procedure as in Experiment 1. We fitted two models with liking rating as the variable to predict. The first model included Contour (curved vs. sharp-angled), Category (computer-made vs. hand-made), Shading (shaded vs. non-shaded), Sex, and the interaction between these factors as fixed effects. The model included participant and stimulus as random effects, as well as random slopes for Contour within these effects. The second model included the interaction of Contour, Category and Shading with the Art experience and Openness to Experience questionnaires as predictors. Two participants did not respond to the questionnaires and were therefore excluded from this analysis. The scores of the questionnaires were centered on their grand mean before the analysis. The model included participant and stimulus as random effects, as well as random slopes within these effects. Each model included an analysis of influential cases as in Experiment 1.

Results

In the first model, influential extreme case analysis gave five values exceeding the recommended cut-off point, which was.077. These participants were removed from the analysis. As in Experiment 1, participants liked the curved drawings ($M = 45.4$, *95% CI* [40.2, 50.6]) more than the sharp-angled drawings ($M = 37.4$, *95% CI* [32, 42.8]), $\beta = 4$, $SE = 1.41$, $t(25) = 2.82$, $p = .0093$, *95% CI* [1.22, 6.74] (Figure 2(b)). They also liked the shaded drawings ($M = 44.6$, *95% CI* [39.4, 50]) more than the non-shaded drawings ($M = 38.2$, *95% CI* [33, 43.4]), $\beta = -3.22$, $SE = 1.33$, $t(21) = -2.41$, $p = .025$, *95% CI* [−5.8, −.64]. In contrast, liking ratings did not differ between the hand-made (*M* = 40.8, *95% CI* [35.5, 46]) and computer-made drawings (*M* = 42, *95% CI* [36.8, 47.4]), $\beta = .64$, *SE* = 1.33, *t*(21.3) = .48, *p* = .64, *95% CI* [−1.95, 3.23]. In this case, men participants (*M* = 46.2, *95% CI* [41, 51.4]) liked the drawings significantly more than women participants (*M* = 36.6, *95% CI* [30.2, 43]), $\beta = -4.81$, *SE* = 1.84, *t*(50) = −2.62, *p* = .012, *95% CI* [−8.42, −1.18]. However, unlike in Experiment 1, the interaction between Category and Sex was non-significant, β = .56, *SE* = .41, *t*(2,345) = 1.36, *p* = .17, *95% CI* [−.24, 1.36] (Figure 3(b)). All other interactions were also non-significant.

In the second model, influential case analysis showed four extreme cases whose value exceeded the recommended cut-off point, which was.078. These participants were therefore excluded from the analysis. Results showed a significant interaction between Shading and Openness to Experience, $\beta = .13$, *SE* = .06, *t*(2,277.3) = 2.2, *p* = .028, *95% CI* [.01, .25]. As Openness to Experience scores increased, liking ratings decreased only for the shaded drawings. Similarly, the interaction between Category and Openness to Experience was significant, $\beta = -.30$, *SE* = .06, *t*(2,277.3) = 4.98, *p* < .001, *95% CI* [−.42, −.18]. As Openness to Experience scores increased, liking ratings decreased only for the computer-made drawings. All other effects and interactions were non-significant.

Relationship between liking tasks. We performed a correlation analysis based on the liking ratings in Experiments 1 and 2. We produced a liking value for each drawing from both experiments. Then, we estimated the bias-corrected and accelerated CI using the bootstrap resampling method considering 1,499 samples as appropriate for a test at the 0.5 and 0.1 level (Davidson & MacKinnon, 2000). Results showed a strong positive correlation between the results of the two experiments, $r_p(46) = .93$, *p* < .001, *95% CI* [.863, .962]. Despite this strong positive correlation between the two experiments, an independent-measure t-test indicated significantly higher liking ratings for the drawings in Experiment 1 compared to Experiment 2, *t*(87) = 2.62, *p* = .010, *95% CI* [1.84, 13.39], *d* = .59.

Discussion

Experiment 2 supported some of the findings of Experiment 1. Participants liked the curved drawings more than the sharp-angled drawings. They also liked the shaded drawings more than the non-shaded drawings. Overall, men participants liked the drawings significantly more than women participants. Importantly, in this case, higher scores in openness to experience did not affect preference for curvature, but predicted decreasing preference for the shaded and computer-made drawings. These results are in striking contrast to those of Experiment 1. They support the remarkable breadth of individual variation in personal preferences reported by previous studies (Corradi et al., 2019b). Lastly, the correlation between liking ratings in Experiments 1 and 2 indicated a consistent preference for the same drawings inside and outside of the laboratory.

Comparing the results from Experiments 1 and 2, the general difference between the values of the ratings in the two experiments stands out. In Experiment 1 the total average of the ratings was 49.1, whereas the total average in Experiment 2 was 41.5. Participants rated the drawings higher in the laboratory than on the internet. This difference might be explained by the different experimental conditions. The participants in Experiment 1 were basically university students who were around 24 years old and were tested in the laboratory. In contrast, the participants in Experiment 2 were from diverse backgrounds with an average age of 34, and tested in a web-based study. In Experiment 2, 5 participants had completed secondary education, 24 had high school or professional training qualifications, 13 were university graduates, 9 were postgraduates, 6 had PhDs, and 2 did not answer the question. Alternatively, it is possible that the close contact with the experimenter in Experiment 1 may have boosted the ratings, while the participants in Experiment 2 did not have such direct contact with the experimenter. According to this idea, we may expect higher ratings in liking tasks conducted in the laboratory than in web-based studies.

In Experiment 3, we proposed testing the hypothesis that what is aesthetically preferred is also preferred for reproduction (Mace & Ward, 2002; Tinio, 2013; Williams et al., 2018) with regard to drawings and preference for curvature. We used the same stimuli to investigate whether the curvature effect was similar when we asked about intention to reproduce the drawings.

Experiment 3

Experiment 3 consisted of an online drawing preference task, asking which drawing participants would prefer to draw from a choice of two. It was a similar task to those in Park et al. (2010) and Williams et al. (2018). We designed it with the open-source Psytoolkit software (Stoet, 2017). The task asked participants to report which drawing from each pair (curved and sharp-angled) they would prefer to draw, as well as the strength of this preference. We expected that participants would prefer to draw the curved drawings for two reasons. The first reason was the visual preference results from Experiments 1 and 2. The second reason was the possible relationship between aesthetic and drawing preference suggested by previous studies (Boyatzis & Eades, 1999; Taylor & Eisenman, 1964; Williams et al., 2018).

Method

Participants. Sixty-seven adult participants (47 female, $M_{\text{age}} = 32.5$, $SD_{\text{age}} = 16.5$) volunteered to participate in the experiment. As in Experiment 2, they were recruited via the institutional students' forums and social networking. The experiment was conducted following the same ethical and experimental guidelines as Experiments 1 and 2.

Materials and procedure. We used the same 48 drawings as in the previous experiments. The task presented each pair of drawings together, one on the left and the other on the right side of the computer screen, until participants responded. Participants were asked to indicate which of the two drawings they would prefer to draw, as well as the strength of this preference using a preference scale from 1 to 7. A score between 1 and 3 indicated a preference for the left-side drawing (1 = strong preference for the left-side drawing), while a score between 5 and 7 indicated a preference for the right-side drawing (7 = strong preference for the right-side drawing). A score of 4 indicated a preference for neither drawing (Park et al., 2010; Williams et al., 2018). Each pair of drawings was presented twice, once with the curved drawing on the left-side, and once with the curved drawing on the right-side, the sharp-angled drawing was also presented on both sides. The drawings were rendered at 400 pixels high, and 400 pixels wide. The task had 8 additional practice trials, and 48 experimental trials. The trial sequence was randomized. Finally, participants completed the same two questionnaires as in Experiment 1 and 2.

As in Experiment 2, participants were required to have a computer screen with a resolution of at least 1,280 × 720 pixels. They were instructed that two drawings would be displayed on the screen, one on the left and the other on the right side. Their task was to indicate which drawing they would prefer to draw and the strength of that preference with a mouse click on the numbers in the relative preference scale. Subsequently, they completed the questionnaires. The experiment lasted about 15 min. Finally, participants were debriefed and thanked.

Data analysis. We fitted two models using the scores 1 to 7 (left/right drawings on the screen) as the variable to predict. The first model included Arrangement (curved/sharp-angled vs. sharp-angled/curved), Category (computer-made vs. hand-made), Sex, and the interaction between these factors as fixed effect factors. In this case, Shading was not included as a factor because some pairs consisted of two shaded drawings but others consisted of a shaded drawing and a non-shaded drawing. The second model included the interaction of Arrangement and Category with the individual differences measures as fixed effects. The models included participant and stimulus as random effects, as well as random slopes for Arrangement within these effects. Lastly, we also conducted an analysis of influential extreme cases as in the previous experiments.

Results

In the first model, there were two influential cases whose values exceeded the recommended cut-off point, which was.067. These participants were therefore removed from the analysis. A significant effect of Arrangement revealed higher preferences for the curved stimuli than for the sharp-angled stimuli, $\beta = 1.1$, $SE = .36$, $t(43.2) = 3.02$, $p = .0042$, *95% CI* [.40, 1.80]. The score (1–7) was significantly lower when the curved stimuli was on the left-side (*M* = 3.66, *95% CI* [3.37, 3.95] than when it was on the right-side (*M* = 4.34, *95% CI* [4.02, 4.65] (Figure 4(a)). The interaction between Arrangement and Category was near significance, *β* = .85, *SE* = .43, *t*(22) = 2, *p* = .058, *95% CI* [−1.66, −.04]. Post-hoc tests revealed higher drawing preference for the curved hand-made stimuli than for the sharp-angled hand-made stimuli, β = 1.1, SE = .36, t(43.2) = 3.02, *p* = .0042. In contrast, there was no significant difference between drawing preference for the curved and sharp-angled computer-made stimuli, *β* = .25, *SE* = .36, *t*(43.2) = .68, *p* = .50 (Figure 4(b)). Lastly, scores did not significantly differ between men and women participants, *β* = .40, *SE* = .25, *t*(71.54) = 1.58, *p* = .12, *95% CI* [−.09, .89]. All other effects or interactions were also non-significant.

In the second model, there was one influential value exceeding the recommended cut-off point, which was.0678. Results revealed no significant effect for Art Experience, *β* = .014, *SE* = .015, *t*(60.8) = .94, *p* = .35, *95% CI* [−.042, .014], or for Openness to Experience, *β* = .028, *SE* = .04, *t*(60.8) = .70, *p* = .48, *95% CI* [−.10, .05]. The interactions were also non-significant.

Relationship between liking scores and drawing preference. We performed correlation analyzes between liking scores and preference choices to examine the relationship between aesthetic and drawing preferences (Williams et al., 2018). First, we grouped the preference choices from Experiment 3 when they were presented in the left-side and the right-side of the screen. This gave a mean drawing preference value to each curved and sharp-angled stimulus. Next, we correlated these values with the liking ratings from Experiments 1 and 2. Lastly, we estimated CIs with the bootstrap resampling method as in the previous experiment. Results showed a moderate positive correlation between liking and drawing preference, $r_p(46) = .327$, *p* = .023, *95% CI* [.081, .557] (Exp. 1 vs. Exp. 3); *r*(46) = 0.296, *p* = .041, *95% CI* [.040, .52] (Exp. 2 vs. Exp. 3). However, liking and drawing preference correlation for the hand-

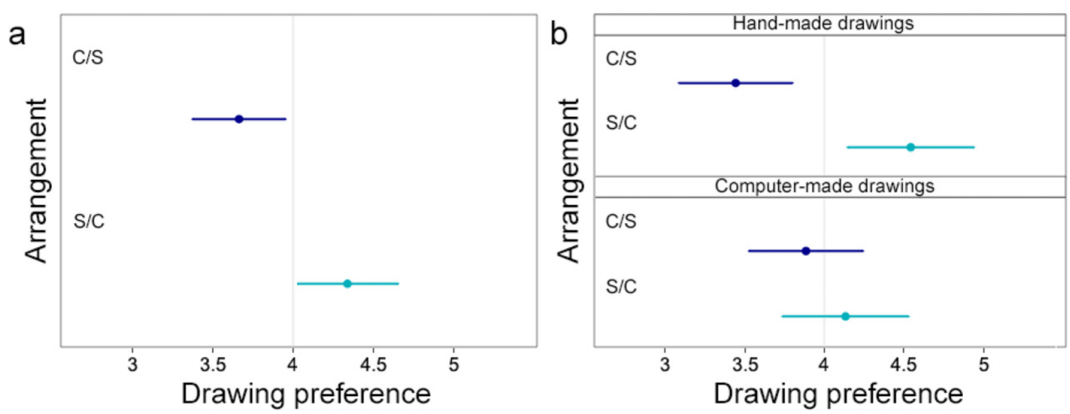

Figure 4. Drawing preference in experiment 3. The vertical axis shows the arrangement of the stimuli (C/S: Curved/Sharp-angled. S/C: Sharp-angled/Curved), and the horizontal axis shows drawing preference scores. Error bars represent 95% CI around the means.

made drawings was higher, but not significant as a consequence of using fewer drawings, $r_p(22) = .392$, $p = .058$, *95% CI* [.094, .677] (Exp. 1 vs. Exp. 3); $r_p(22) = .386$, $p = .062$, *95% CI* [−.052, .645] (Exp. 2 vs. Exp. 3). In contrast, the correlation between liking and drawing preference for the computer-made drawings was lower and non-significant, $r_p(22) = .152$, $p = .478$, *95% CI* [−.318, .492] (Exp. 1 vs. Exp. 3); $r_p(22) = .141$, $p = .51$, *95% CI* [−.253, .464] (Exp. 2 vs. Exp. 3) (Figure 5). Overall, these results moderately support the association between aesthetic and drawing preference for drawings of commonly-used objects, especially when those drawings are designed by hand.

Discussion

The finding of a preference for drawing curved images over sharp-angled images is in line with the results of Experiments 1 and 2. However, participants' drawing preference for the curved stimuli appeared only with hand-made drawings, not with

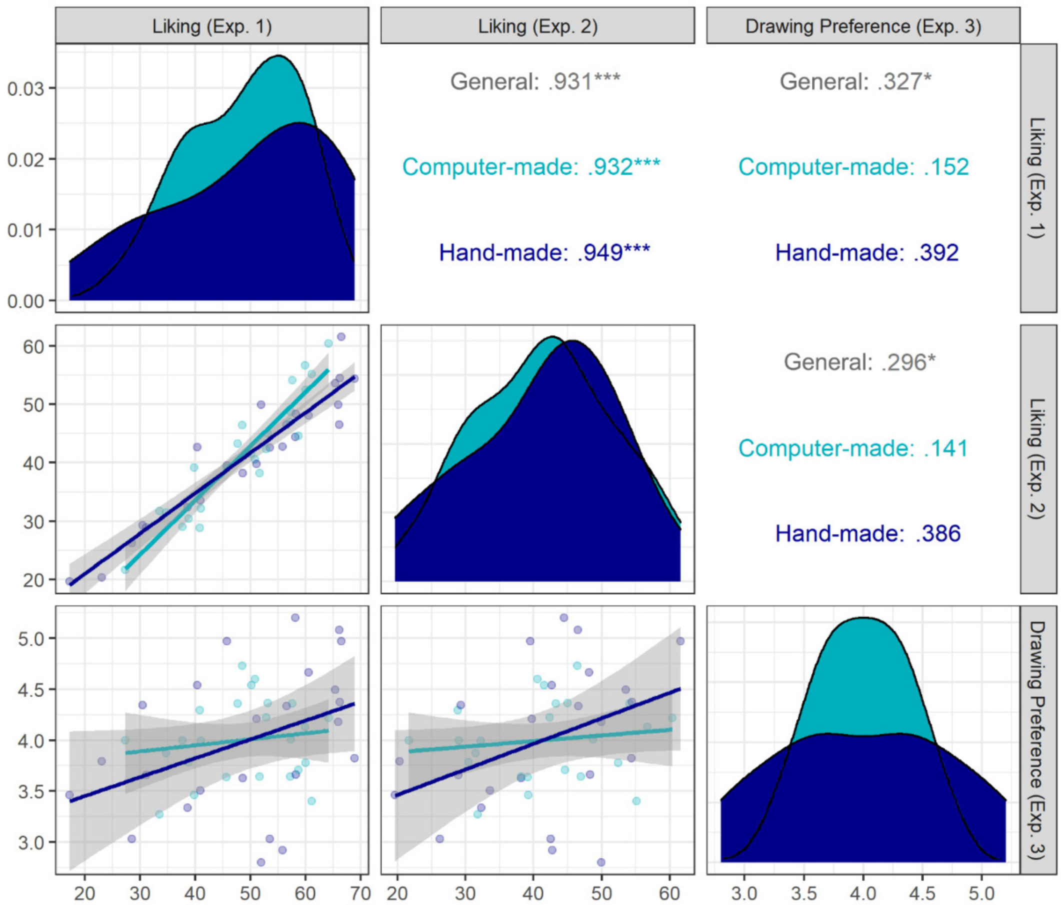

Figure 5. Correlation matrix of the three experiments. Diagonal: density plots of the computer-made and hand-made drawings. Left-bottom: scatterplots of the relationship between data from the hand-made and computer-made drawings. Right-top: general, computer-made, and hand-made drawings correlations. *Note.* ***$p < .001$, **$p < .01$, *$p < .05$.

computer-made drawings. Correlation analyzes indicated a moderate relationship between aesthetic and drawing production preference. Interestingly, this relationship was stronger with the hand-made drawings than with the computer-made drawings. These findings support a specific relationship between aesthetic preference and production preference only with hand-made drawings. In other words, the hand-made drawings that participants liked most were also what they would prefer to draw. This finding may highlight the link between hand-made stimuli and human presence (Schroll et al., 2018). Participants may have perceived the hand-made drawings as more natural or realistic stimuli to be reproduced. In contrast, they may have perceived the computer-made drawings as more artificial or unrealistic stimuli to be reproduced.

On the other hand, neither sex, art experience, nor openness to experience demonstrated any relationship to preferring to draw the curved version. These results are in line with the inconsistent influence of some individual variables in preference for curvature using various kinds of stimuli (e.g., Chuquichambi et al., 2021; Corradi et al., 2019a). Moreover, they also add to the idea that individual preferences coexist with remarkable individual variation (Corradi et al., 2019b).

General Discussion

In this study, we examined preference for curvature using drawings of commonly-used objects, and the relationship of that preference with drawing preference. Experiments 1 and 2 assessed how much people liked the drawings of the objects. Experiment 1 was carried out in the laboratory with undergraduate students and Experiment 2 was a web-based study with a more varied sample of participants. Experiment 3 assessed drawing preference choices using a relative preference scale. In the three experiments, we also measured art experience and openness to experience.

Experiments 1 and 2 clearly showed a preference for the curved drawings over the sharp-angled drawings with quite similar effect sizes in both experiments. This finding is in line with other studies that have compared the two kinds of drawings (Bertamini & Sinico, 2021; Chuquichambi et al., 2021) and quite a few studies that have used other types of stimuli (Coburn et al., 2020; Corradi & Munar, 2020; Gómez-Puerto et al., 2016, 2017; Palumbo et al., 2020). We can conclude that the well-established preference for curvature is also significant using these kinds of drawings in two different experimental contexts, the laboratory and on a website, and two relatively different samples of participants.

Another result common to Experiments 1 and 2 is that participants liked the shaded drawings more than the non-shaded drawings. This result also agrees with the findings from Chuquichambi et al. (2021), and suggests that drawing characteristics and stylistic design influence preference judgement. In addition, men liked the drawings in general more than women in Experiment 2. This difference was only significant with the computer-made drawings in Experiment 1. However, sex did not exhibit an influence on preference for curvature in either of the two experiments. In other words, the curvature effect was similar for men and women in both experiments.

On the same lines, sex did not exhibit a significant effect on preference for curvature in Experiment 3. Overall, these findings are in line with some studies suggesting that sex differences do not modulate preference for curvature (Corradi et al., 2019a; Jadva, Hines, & Golombok, 2010; Palumbo, Ruta, & Bertamini, 2015).

With regard to the hypothesis suggesting that stimuli preferred for creation are similar to aesthetically preferred stimuli (Tinio, 2013; Williams et al., 2018), we found that the curved images were also significantly preferred for drawing over the sharp-angled images. However, this preference was only present for hand-made drawings and not for computer-made drawings. This suggests that a viewer's preference for curved drawings can be linked to its aesthetic production. Indeed, Tinio (2013) proposed that the aesthetic experience of an artwork could be interpreted as the result of its aesthetic production. Furthermore, we can add the study of the contour feature to other studies exploring the relationship between aesthetic production and preference with specific low-level features such as symmetry (Humphrey, 1997; Washburn & Humphrey, 2001) and complexity (Nadal, Munar, Marty, & Cela-Conde, 2010; Taylor & Eisenman, 1964).

Correlation analyzes supported a moderate relationship between aesthetic (Experiment 1 and 2) and drawing preference (Experiment 3). Interestingly, these correlations were stronger with the hand-made drawings than with the computer-made drawings. One possible explanation of this finding comes from the idea that drawing an image really means to draw by hand. Drawing a computer-made image could be felt to be unnatural and/or more difficult. Hence, the curvature effect would not work for such an unrealistic situation. Another explanation may be based on the perception that hand-made images are directly created by other people and that could motivate participants to replicate something similar to what they like more. In contrast, the reasons for them to replicate something that is basically made by a machine (computer) might not be based on liking and could be more pragmatic. A third hypothesis is based on the idea that both preference for curvature and *handmade-ness* are related to the perception of human presence. This feeling of human presence would link visual liking and drawing preference. Previous studies have suggested that preference for curvature can be based on the fact that human beings find neotenic traits more attractive (Bertamini & Palumbo, 2015; Bertamini, Palumbo, Gheorghes, & Galatsidas, 2016). Neoteny is the retention of juvenile physical traits in the adult: a round head and large round eyes, among others. With regard to handmade-ness, Schroll et al. (2018) showed that handwritten typefaces create perceptions of human presence and humanization cues, which lead to more favorable evaluations. A fourth hypothesis is that the relationship between liking and hand-made drawing preference is based on the fact that both are directly related to art. The hand-made drawings could be perceived as more artistic than the computer-made drawings, and participants may prefer to draw artistically according to their visual liking, but not when they draw something that they would not consider artistic. According to Dinham (1989), handmade drawing has been regarded as the founding discipline of the Western artist's creative activity. It is possible that participants did not perceive artistic quality in the computer-made drawings, and their decision about what to draw was not based on what they liked most.

Using geometric shapes, Williams et al. (2018) also showed that drawing preference increased with higher aesthetic ratings regardless of expertize. Despite not finding any interaction between drawing preference and expertize in the rating data, they indicated that the relationship between aesthetic preference and artistic preference for production varied with expertize. The statement was based on findings that artists' gaze behavior was influenced by what they would prefer to draw (Kozbelt, Seidel, ElBassiouny, Mark, & Owen, 2010). We did not find any influence of art experience in our results. However, we did not record eye movements or include a real group of experts. Instead, we used an Art Experience questionnaire with a range from 0 to 48, which gave an average score of 17.03 with a standard deviation of 8.69, quite similar to the values from Experiment 1 and 2. Therefore, most of our participants were not experts.

Nonetheless, results from Experiment 1 showed that participants with higher art experience liked the hand-made drawings more than the computer-made drawings, although the results from Experiment 2 did not show this trend. Our interpretation is that it could be a weak effect depending on the participants' level of art experience. Similarly, although participants who were more open to experience liked the curved drawings more than participants who were less open to experience in Experiment 1, the results from Experiment 2 and 3 did not show this pattern. The results from Experiment 2 showed that participants who were more open to experience liked the shaded and the computer-made drawings more, but results from Experiment 1 did not show these effects. Overall, we conclude that the influence of these individual differences on the preference for these specific characteristics are rather too weak to be replicated in similar experiments, at least with the kind of stimuli and sample we used.

We believe that the understanding of the relationship between preference and the production of drawings with different contour lines needs to be complemented with different samples of participants. Target groups might include those with artistic backgrounds or with advanced drawing skills. Furthermore, although sex exhibited an influence on preference for drawings in the first two experiments, this influence needs to be examined with balanced samples of male and female participants. An interesting approach also may be to ask participants how challenging they perceive the reproduction of a given object. In this way, we may be able to differentiate between participants desire to reproduce a certain drawing and the level of their drawing skills. Lastly, the production of drawings deserves testing with direct drawing tasks in which, for example, participants are asked to indicate their affective state or preference by actually producing a drawing. This idea was explored by an early study from Lundholm (1920). That author found that participants drew lines with predominantly sharp angles to express an unpleasant feeling or tone. In contrast, participants drew mainly curved, symmetrical and continuous lines to express beauty. Therefore, we could reinforce our conclusions by asking participants to draw what they like the most from among a few options.

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Data Accessibility Statement

The datasets generated and analyzed during the current study are available on the Open Science Framework: https://osf.io/2u5rq/

Declaration of Conflicting Interests

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ORCID iDs

Erick G. Chuquichambi https://orcid.org/0000-0001-5389-283X
Guido B. Corradi https://orcid.org/0000-0001-9163-6829

Supplemental Material

Supplemental material for this article is available online.

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Author Biographies

Erick G. Chuquichambi: I am a PhD student in Human Cognition and Evolution at the University of the Balearic Islands. I am a member of the Human Evolution and Cognition group. My research focuses on Empirical Aesthetics and Social Cognition.

Daniela Sarria: I am a graduate student in psychology at the University of the Balearic Islands, currently working as a UX designer. I am a member of the Human Evolution and Cognition group. My research focuses on Empirical Aesthetics.

Guido B. Corradi: I am a researcher and teacher at Universidad Camilo José Cela. I am a member of the Human Evolution and Cognition group. My research interests are related to human visual preferences.

Enric Munar: I am a professor and researcher at the University of Balearic Islands and coordinate the PhD programme in Human Cognition and Evolution. My field of expertise is perception and attention from a cognitive point of view. Our research group – Human Evolution and Cognition– especially works on Empirical Aesthetics and Moral Psychology. Despite I worked on both fields and others related to cognition, I have focused on Empirical Aesthetics over the last years and particularly on preference based on low-level visual properties, more specifically on preference for curvature.

4. GENERAL DISCUSSION

In the present dissertation, we contribute to the literature on preference for visual curvature in a twofold manner. First, we provide a synthesis of the empirical evidence on this effect and indicate its possible sources of heterogeneity. Second, we present a series of studies that examined the robustness of preference for curvature by addressing possible modulating factors. In these studies, we have identified some strengths, weaknesses, and challenges arising from the literature. In the next section, we summarize the critical findings of each study. Afterward, we progress into a more in-depth discussion of the implications of the findings. Finally, we propose some current challenges and future directions for upcoming research on curvature preference.

4.1. Summary of research findings

In *How universal is preference for visual curvature? A systematic review and meta-analysis* (Chuquichambi, Vartanian et al., 2022), we presented the first literature review focusing on the quantitative aspects of preference for curvature. We identified 81 studies from multidisciplinary fields meeting our eligibility criteria. However, 20 studies did not report the necessary data to calculate the effect sizes. Therefore, this work included 61 studies, which provided 106 independent samples of participants and 309 effect sizes. Data were analyzed using a three-level random-effects model to account for the sampling variance of each effect size (level 1), variance among effect sizes within-studies (level 2), and variance among effect sizes between-studies (level 3). Our results indicated a moderate magnitude of preference for curvature. However, we also found that this effect coexists with substantial heterogeneity variance between-studies. Additional moderator models revealed significant moderating effects of factors such as task (artistic, economic, semantic, hedonic, and magnetic), stimulus type (real, meaningless, spatial design, and symbol), presentation time (limited vs. unlimited), and expertise (non-experts, quasi-experts, and experts). Specifically, the magnitude of preference for curvature was large for semantic tasks, moderate for hedonic tasks, small-to-moderate for artistic and economic tasks, and small for magnetic tasks. The effect was moderate-to-large for meaningless stimuli, moderate for real stimuli, small-to-moderate for symbolic stimuli, and small for spatial design stimuli. Regarding the presentation time of the stimulus, the magnitude of the effect for the limited presentation time was greater than for the unlimited presentation time. Lastly, preference for curvature was moderate and significant for non-expert participants, but small and non-significant for expert participants.

In *Circles are detected faster than downward-pointing triangles in a speeded response task*

(Chuquichambi et al., 2020), we examined whether curved shapes captured attention faster than angular shapes. In two experiments, participants were presented with matrices containing a target shape (circle or downward-pointing triangle) and multiple distractors in a speeded response task. They were asked to detect whether the target stimulus was present or absent. The results indicated that circles were detected faster than downward-pointing triangles. However, the difference between target stimuli decreased as the number of elements in the matrix increased (i.e., matrix size). We propose that attentional processes might be tuned to curved features in visual search displays. Noteworthy, our findings could also shed light on the possible link between perceptual sensitivity and preference associated with curvature.

In *When symmetric and curved visual contours meet intentional instructions: Hedonic value and preference* (Chuquichambi, Corradi et al., 2021), we examined the hedonic tone associated with contour and symmetry features presenting meaningless stimuli in an implicit affective SRC[3] task. We also examined the preference for these stimuli using an explicit liking rating task. The implicit and explicit tasks included instructed mindsets to induce participants to focus on the symmetry and contour features in different parts of the task. This way, we could investigate the interaction between low-level features and the influence of task-related variables (i.e., induced mindsets) in preference for curvature. In the implicit task, we found the expected compatibility of symmetry and curvature with positive hedonic tone. In the explicit task, the liking of the participants for symmetrical and curved stimuli was higher than their liking for asymmetrical and angular stimuli. Symmetrical-curved stimuli showed higher implicit positive valence and higher explicit liking ratings, suggesting an additive interaction between these features on preference. However, we did not find any correlation between the implicit and explicit results. This finding suggests that implicit and explicit measures rely on different cognitive processes related to conscious and unconscious evaluations, respectively.

In *Shape familiarity modulates preference for curvature in drawings of common-use objects* (Chuquichambi, Palumbo et al., 2021), we investigated whether familiarity with the shape of curved and sharp-angled object drawings influenced the preference for these drawings. We also explored whether individual differences modulated preference for curvature. In Experiment 1, participants responded to a liking rating task. In Experiment 2, participants responded to a two-alternative forced choice task simulating approach/avoidance actions. In both experiments, participants also responded to a familiarity selection task and a set of individual questionnaires. We found a consistent preference for the curved object drawings in both experiments. Moreover, participants selected the objects with curved shapes as

[3]SRC refers to the stimulus-response compatibility effect.

the most familiar, then they selected both object shapes as equally familiar, and last they selected the objects with sharp-angled shapes as the least familiar. In both experiments, preference for curvature was present when the objects with curved shapes were selected as the most familiar, and when the shape of both objects was selected as equally familiar. However, there was no preference for curvature or angularity when the objects with sharp-angled shapes were selected as the most familiar. In Experiment 2, while higher scores in the unconventionality facet predicted a decreasing preference for curvature, higher scores in the holistic big picture and affective types of intuition predicted an increasing preference for curvature. Together, we concluded that familiarity with the shape of objects modulates preference for curvature, and proposed curvature as one of the fluency-enhancing variables explaining the relationship between prototypicality and attractiveness.

In *Humans prefer to see and imagine drawing curved objects* (Chuquichambi, Sarria et al., 2022), we investigated the relationship between preference for curvature and drawing production preference using drawings of common-use objects. We also explored the influence of participants' individual differences in this relationship. Experiment 1 consisted of a liking rating task conducted in the laboratory and recruiting undergraduate students. Experiment 2 consisted of the same liking task conducted online and recruiting a more varied sample of participants. Experiment 3 consisted of a web-based drawing choice task. All experiments included questionnaires on art experience and openness to experience. In Experiments 1 and 2, participants liked the curved drawings more than the sharp-angled ones. In Experiment 3, participants preferred to draw the curved drawings more than the sharp-angled ones. However, while the effect was significant with hand-made drawings, it did not reach significance with computer-made drawings. Additional correlation analyses revealed a moderate positive relationship between liking ratings (Experiments 1 and 2) and drawing preference (Experiment 3). This relationship was mainly explained by the hand-made drawings. On the other hand, neither sex, neither art experience nor openness to experience influenced preference for curvature in any consistent manner. We concluded that participants prefer to see and imagine drawing curved objects, especially when these are hand-made.

To summarize, the present dissertation synthesizes the literature on preference for curvature and yields new empirical evidence addressing the possible modulator factors of the effect. *Table 2* presents an overview of the experimental design and main findings of each study.

```r
# Get a table to summarize the experimental design of each empirical study.
table2 <- data.frame(Cat = c("Main question", "N Studies","Stimuli","Task",
    "Additional measures","Main finding"),`Paper 1` = c("How universal is the
```

```
    effect?","61 studies","106 samples,  309 effect sizes", "Systematic review
    and Meta-analysis", "Moderator variables: Task, Stimulus type, Presentation time,
    Expertise","A reliable, moderate (g=.39), but not universal effect."), `Paper 2`
    = c("Does curvature capture attention?","2", "Geometric shapes","Speeded
    response","No","Faster processing of curved shapes: perceptual sensitivity."),
    `Paper 3` = c("How symmetry and contour hedonic values interact?","1",
    "Meaningless patterns","Affective S-R compatibility, Liking ratings","No",
    "People associate symmetry and curvature with positive values."), `Paper 4`=
    c("How familiarity influences the effect?","2","Object drawings", "Liking
    ratings, 2AFC, Familiarity", "Art experience* Openness to experience,
    Unconventionality, Types of intuition*","Shape familiarity modulates the effect."),
    `Paper 5` = c("Is the effect related to drawing preference?", "3", "Object
    drawings","Liking ratings, Drawing choice", "Art experience, Openness to
    experience","People prefer to draw what they like to see: curved objects."))
kable(table2,col.names=c("","1","2","3","4","5"), align=rep('c', 4), escape = F,
      caption ="Summary of the experimental design of each empirical study.") %>%
      kable_styling(latex_options = "HOLD_position", full_width = TRUE) %>%
  add_footnote(c("Chuquichambi, Vartanian et al. (2022)", "Chuquichambi et al. (2020)",
  "Chuquichambi, Corradi et al. (2021)","Chuquichambi, Palumbo et al. (2021)",
  "Chuquichambi, Sarria et al. (2022)"), notation = "number") %>%
  add_footnote("Art experience: Art interest, Art knowledge.", notation="symbol") %>%
  add_footnote("Types of intuition: Big picture, Abstract, Inferential, Affective.",
             notation="symbol")
```

Table 2: Summary of the experimental design of each empirical study.

	1	2	3	4	5
Main question	How universal is the effect?	Does curvature capture attention?	How symmetry and contour hedonic values interact?	How familiarity influences the effect?	Is the effect related to drawing preference?
N Studies	61 studies	2	1	2	3
Stimuli	106 samples, 309 effect sizes	Geometric shapes	Meaningless patterns	Object drawings	Object drawings
Task	Systematic review and Meta-analysis	Speeded response	Affective S-R compatibility, Liking ratings	Liking ratings, 2AFC, Familiarity	Liking ratings, Drawing choice
Additional measures	Moderator variables: Task, Stimulus type, Presentation time, Expertise	No	No	Art experience* Openness to experience, Unconvention-ality, Types of intuition*	Art experience, Openness to experience
Main finding	A reliable, moderate (g=.39), but not universal effect.	Faster processing of curved shapes: perceptual sensitivity.	People associate symmetry and curvature with positive values.	Shape familiarity modulates the effect.	People prefer to draw what they like to see: curved objects.

[1] Chuquichambi, Vartanian et al. (2022)

[2] Chuquichambi et al. (2020)

[3] Chuquichambi, Corradi et al. (2021)

[4] Chuquichambi, Palumbo et al. (2021)

[5] Chuquichambi, Sarria et al. (2022)

[*] Art experience: Art interest, Art knowledge.

[*] Types of intuition: Big picture, Abstract, Inferential, Affective.

4.2. A robust but flexible effect

Preference for visual curvature has been reviewed from a conceptual and theoretical perspective (Corradi & Munar, 2020; Gómez-Puerto et al., 2016). However, as noted by Corradi (2019), we still have some caveats to overcome regarding the accumulation of evidence in the literature. One of the most important caveats was the lack of a meta-analysis assessing how universal preference for curvature truly is. Here, we conducted this study and found a reliable and moderate magnitude of this preference. This finding supported the notion of preference for curvature as a robust and well-known effect. However, we also found that the effect coexists with substantial heterogeneity between studies, leaving the door open to how additional variables may contribute to or challenge this preference.

4.2.1. Beyond mere preference

In Chuquichambi, Corradi et al. (2021), we found that symmetry and contour features interact in an additive manner. While symmetry and curvature are positive-valenced features, asymmetry and angularity are negative-valenced features. These findings are in line with Makin's assumption (2017) that consistency between different parts of the image is good, even if that 'consistency' means double negative valence. However, we do not assume that this relationship would be present with other features because any apparent aesthetic law is potentially malleable (Makin, 2017). Aesthetic experience typically relates to the gestalt, or whole, rather than the sum of any isolated parts (Arnheim, 1974). That is, we cannot define general preferences by assessing one stimulus dimension at a time because stimuli are multidimensional. Instead, preferences emerge from the complex interplay of the features that characterize a given stimulus, and they are likely to be dominated by the most salient feature.

Curved shapes may capture our attention faster than angular shapes (Chuquichambi et al., 2020) because of the affective values associated with curvature (Chuquichambi, Corradi et al., 2021). In Chuquichambi et al. (2020), we suggested a possible link between the perceptual sensitivity for curved contours and hedonic preference for curvature. We not only extract perceptual information from a stimulus, but assign a hedonic value to it (Skov & Nadal, 2021). Therefore, perception and valuation of curved contours are intrinsically linked processes. Curvature is a relevant feature in the way shape is encoded in the brain (Pasupathy, 2006). Specifically, area V4 and posterior inferior temporal cortex have been suggested to provide a physiological basis for the explicit representation of curvature (Pasupathy & Connor, 1999, 2001, 2002). It may be possible that the relative advantage of the human visual system to process curvature is related to the statistics of the natural environment in which the system has evolved

(Bertamini et al., 2019). This idea would be in line with some stimulus features that facilitate fluent processing. Indeed, previous studies employed recognition speed as an indicator of fluency (Checkosky & Whitlock, 1973; Reber et al., 1998). The faster and more efficiently we process a given stimulus, the more positively it will be evaluated (Spehar et al., 2015). For example, symmetrical patterns may be preferred because symmetry facilitates fluent processing (Reber, 2002). Therefore, we suggest that curvature induces a similar pattern of processing and acts as a fluency-enhancing variable (Corradi & Munar, 2020). Together, these findings provide support to the idea that curvature preference involves a sensory-motor and affective component.

The fluency processing of a given stimulus may be related to its familiarity because of the prototypicality-preference relationship. Natural structured environments are easier for us to process. In this vein, familiarity with a stimulus may act as a signal to the neural system that a particular stimulus mimics our ancestral environment in its informational structure. In Chuquichambi, Palumbo et al. (2021), we tested the possibility that preference for curved objects depended on familiarity with the shape of those objects. Our findings supported familiarity as a strong predictor of preference for curvature. However, familiarity was not the only factor explaining the effect because participants also preferred curved objects when they perceived curved and angular shapes as equally familiar. Furthermore, participants did not prefer the angular objects when they perceived these stimuli as the most familiar. Overall, these findings support the idea that prototypical stimuli are easier to process and hence are evaluated more positively. However, they also indicate that other variables affect contour preference in some unpredictable ways.

People's preferences are related to the object's perceptual features and depend on contextual factors that modulate neural activity in both perceptual and affective systems. In other words, preference for a given object is largely determined by the perceptual representation and hedonic values associated with that object. However, we should expect any apparent universal preference to be modulated by contextual factors or sensory cues, such as stimulus features. The use of instructed mindsets provides a good example. In Chuquichambi, Corradi et al. (2021), we demonstrated that preceding cues and instructions affect participants' expectations. This idea would be an example of the fact that framing[4] influences the hedonic valuation of an object, as do other sensory cues (Skov & Nadal, 2019). Indeed, in Chuquichambi, Sarria et al. (2022), we found that curved drawings were liked more than angular drawings. Similarly, participants preferred to draw curved drawings more than angular drawings. However, this preference only appeared when the drawings were made by hand and not when they were made using a computer.

[4]Framing refers to a catchall term for a number of different ways by which object-extrinsic cues and information can bias the way a sensory object is processed and valuated (Skov and Nadal, 2019).

Together, these findings show how the effect of curvature might differ depending on sensory characteristics related to the stimulus.

On the whole, we propose that preference for visual curvature extends beyond mere perceptual information. It involves both a sensory-motor and an affective component. It is also linked to familiarity, and perceptual and semantic fluency. Indeed, in our meta-analysis (Chuquichambi, Vartanian et al., 2022), we were able to include most of the studies presented in this dissertation (Chuquichambi, Corradi et al., 2021; Chuquichambi, Palumbo et al., 2022, Chuquichambi, Sarria et al., 2022), and identified some of the factors that modulate the magnitude of the effect of curvature. Importantly, we suggested that the next frontier in this line of research involved identifying the functional link between the sensory perception and hedonic valuation of contours. This idea would support that the mechanisms for aesthetic judgements could be directly linked to the functional characteristics of the visual brain. Specifically, the apparent increased sensitivity to detect curved features in visual search displays may frame the neurophysiological basis of preference for curvature (Andrews et al., 1973; Bertamini et al., 2019; Pasupathy, 2006; Pasupathy & Connor, 1999, 2001, 2002; Treisman & Gormican, 1988; Wilson et al., 1997; Wolfe et al., 1992). The fluency account could help us to understand that observers' contour preferences may be linked to the perceptual sensitivity to such a feature. However, this hypothesis remains to be further explored because the process by which visual perception moves to aesthetic judgements in the brain is largely unexplored (Isik & Vessel, 2021), and remains a focus of research for upcoming neuroscientific studies.

4.2.2. The view from neurophysiology

Perceptual and hedonic processing of visual contour in the human brain remains uncertain. Contour features have been linked to the basis of shape representation and object recognition. Pasupathy (2006) argued that the primate visual system may extract contour features as intermediate-level shape primitives beyond oriented edges, in the process of recognizing visual shape. Yue et al. (2014) found a network of cortical areas selective for the processing of curved features in macaque monkeys. This network included three hierarchically organized regions within the ventral visual pathway: a bilateral posterior curvature-biased patch (PCP) located in the near-foveal representation of dorsal V4, a bilateral middle curvature-biased patch (MCP) located on the ventral lip of the posterior superior temporal sulcus (STS) in the posterior region of the inferior temporal cortex, and a smaller anterior curvature-biased patch (ACP) located below the STS in the anterior region of the inferior temporal cortex. The MCP was located dorsal-posterior to the posterior face patch (PFP). They were found to be elongated and collinear, sharing a common boundary, and at lower thresholds, they overlapped. Consequently, the proximity of the curvature-processing network to the face-processing network may be based on a functional link among these networks. In a subsequent study, Yue et al. (2020) found three curvature-preferring patches in the human visual cortex, demonstrating a specialized cortical network for curvature processing in humans. Other studies also found cortical areas with a preference for curvature processing extending from early visual areas to the anterior inferior temporal cortex in both adult and infant monkeys (Arcaro & Livingstone, 2017; Srihasam et al., 2014). Thus, it may be possible that dedicated neural circuits exist for curvature processing.

Curvature may be a proto-organizing dimension of the ventral visual stream. Specifically, regions V4 and posterior inferior temporal cortex have been proposed as curvature selectivity areas (Brincat & Connor, 2004; Habak et al., 2004; Kayaert et al., 2005; Ponce et al., 2017). El-Shamayleh and Pasupathy (2016) proposed contour curvature as a basis for size-invariant object representation in the visual cortex, and area V4 as a foundation for behaviorally relevant object codes. Carlson et al. (2011) proposed that the curvature bias was likely to produce sparser object coding in area V4. Sparse coding has strong implications for computational efficiency, metabolic efficiency, and memory storage. Furthermore, sparse coding is an important goal of sensory transformation because it increases representational capacity and reduces metabolic energy requirements. The formal features of objects in natural scenes might have created evolutionary pressure on our visual system to develop neural circuits that have made us sensitive to those features. From this perspective, the sensitivity to curvature may be explained because this feature enhances sparseness in the brain. An example of such activity would be related to the detection and recognition of animacy. The primate visual system is highly tuned for the detection and recognition of animacy (Long et al., 2018). Animacy is a key organizing principle of object representations in the human ventral temporal cortex. A substantial proportion of animacy (de)coding can be explained by low- and mid-level visual features. Curvature is a relevant feature for animate/inanimate categorization (Yetter et al., 2021). Animate objects tend to be more curvilinear than inanimate objects (Kurbat, 1997; Levin et al., 2001). Indeed, small objects tend to be curved because they are made to be hand-held, and animals have few if any hard corners and are the curviest images (Konkle & Oliva, 2011; Levin et al., 2001; Long et al., 2016, 2017, 2018). Therefore, animacy provides a plausible scenario whereby we may be sensitive to curvature, among other features. The processing of these low- and mid-level perceptual features underlies any neural response associated with the high-level categorical organization and representation of objects. Therefore, the neurophysiological basis of curvature sensitivity may help us shed light on the neural basis of preference for curvature.

4.2.3. Does the effect depend on between-subject variation?

Child (1962) conceived that the appraisal of art was influenced by individual characteristics such as people's experience with art, independent thinking, openness to new experiences, and attraction to challenges. The expertise of the participants showed to influence preference for curvature in aesthetic judgements (Silvia & Barona, 2009) and approach-avoidance decisions (Vartanian et al., 2019). However, its influence on the curvature effect remains unclear due to the mixed findings among studies. Ho (2020) suggested that the small samples of expert participants may explain why expertise appears to affect preference for curvature only under specific conditions. This author collected data from 2081 participants who rated perceived beauty or perceived intimacy of indoor architectural spaces and building exteriors. However, only 94 participants could be considered experts or quasi-experts in architecture (59 architects and 35 architecture students). Her findings showed that while non-experts and architecture students perceived curvilinear buildings as more beautiful than rectilinear ones, this effect did not reach significance with experts. Similarly, while non-experts rated curvilinear buildings as more intimate than rectilinear ones, this effect was not significant with architecture students. These results may be interpreted as expertise modulating preference for curvature. However, they should be carefully considered because of the small number of architects and architecture students in each subgroup of participants.

In two studies (Chuquichambi, Palumbo et al., 2021; Chuquichambi, Sarria et al., 2022), we did not find a consistent influence of art experience on preference for curvature. However, we did not recruit real experts or quasi-expert participants as other studies did (Corradi, Belman et al., 2019; Dazkir & Read, 2012; Ho, 2020; Madani, 2007; Palumbo et al., 2020; Vartanian et al., 2019). Instead, we measured art experience as a continuous trait in our sample using a self-reported questionnaire as other studies (Corradi, Chuquichambi et al., 2020; Cotter et al., 2017; Leder & Carbon, 2005; Munar et al., 2023; Ruta et al., 2019, 2021; Silvia & Barona, 2009). These different approaches may have contributed to the mixed evidence reported in the literature. For example, while some studies found an influence of art experience on curvature preference (Cotter et al., 2017; Silvia & Barona), other studies did not find this effect (Corradi, Chuquichambi et al., 2020; Leder & Carbon, 2005; Munar et al., 2023; Ruta et al., 2019, 2021). Noteworthy, differences among stimuli should also be considered because expertise might moderate preference for curvature only when the objects are specific to the field of expertise of the participants (Corradi, Belman et al., 2019). Together, the literature and our meta-analysis results suggest that expertise tends to decrease preference for curved stimuli while increasing preference for angular stimuli. However, given the current scenario, we need a comprehensive study on the role of expertise in preference for curvature using various types of stimuli.

Regarding other individual factors, openness to experience seems a good candidate to modulate preference for curvature (Corradi, Belman et al., 2019, 2020; Cotter et al., 2017; Ruta et al., 2021). Cotter et al. (2017) found that higher levels of openness to experience led to a greater preference for curved irregular polygons but not for regular polygons. In contrast, subsequent studies found this effect neither in meaningless stimuli (Corradi, Belman et al., 2019; Corradi, Chuquichambi et al., 2020), nor in meaningful stimuli (Corradi, Belman et al., 2019; Ruta et al., 2021). Our results are in this line using representational stimuli such as object drawings (Chuquichambi, Palumbo et al. 2021; Chuquichambi, Sarria et al., 2022). Therefore, we support the idea of a weak and uncertain influence of openness to experience on preference for curvature. Unfortunately, since openness to experience is measured as a continuous personality trait in the population, it was not possible to estimate its moderator effect in the meta-analysis (Chuquichambi, Vartanian et al., 2022). Noteworthy, in Chuquichambi, Palumbo et al. (2021), we found that the unconventionality personality facet and some types of intuition (holistic big picture and affective) could predict distinct patterns of contour preference. Overall, these findings also support that we need a systematic study to understand the role of individual characteristics in preference for curvature.

4.3. Current challenges and future directions

The study of the effect of preference for curvature is part of the emerging field of Neuroaesthetics. Therefore, future research must integrate studies on this topic with neuroscientific evidence (Leder & Nadal, 2014). Bar and Neta (2007) found an increased bilateral amygdala activation for sharp-angled objects than for curved objects, for both real objects and novel patterns. However, Larson et al. (2009) found no difference between downward-pointing triangles and circles in the involvement of the amygdala and associated brain regions related to negative valence and threat detection. Furthermore, studies such as Vartanian et al. (2013) and Banaei et al. (2017) revealed that judging the beauty of curvilinear architectural spaces is associated with increased activity in the ACC[5]. The ACC is part of the core circuit for aesthetic processing (Brown et al., 2011) and is strongly involved in the reward processing and emotional salience of objects. These findings might underline the role of emotion, motivation, learning,

[5] Anterior Cingulate Cortex.

and reward in preference for curvature. However, how the hedonic value and perceptual sensitivity to curvature can be parsed at the neural level remains far from be clear. Therefore, we need to review our current knowledge on curvature preference derived from electrophysiological and neuroimaging studies. This way, we would be able to advance the understanding of the neural underpinnings of this preference.

What we like or dislike is not merely a response to object features such as curvature, but it also due to a remarkable breadth of individual variation. Future studies could also disentangle the neural pathways of individual differences from the evolutionary pathways that make us broadly sensitive to curvature. This objective cannot be achieved without understanding individual and general preferences at a behavioural level. Noteworthy, it could help us open the scope of future studies on specific target populations that might be characterized by distinct patterns of contour preference. For example, this idea would be particularly relevant for people with psychiatric conditions such as ASD[6]. Previous research suggested that while neurotypical individuals prefer curved contours over sharp-angled ones, individuals with ASD prefer rectilinear shapes over curved ones (Belin et al., 2017). Compared to neurotypical individuals, those with ASD are characterized by a diminished preference for curvilinear interior spaces (Palumbo et al., 2020). Furthermore, compared to neurotypical children, those with ASD look less at curved lines and figures than at rectilinear ones (Carrozza & Fabio, 2020). This distinct pattern of preference may be linked to the dysfunctional emotional development and multisensory integration impairment associated with ASD. For example, children with ASD show difficulties in making non-arbitrary correspondences such as the kiki-bouba effect (Gold & Segal, 2017; Król & Ferenc, 2019; Occelli et al., 2013; Ramachandran & Oberman, 2006). Oberman and Ramachandran (2008) showed that while 88% of neurotypical children would pick a curvilinear shape as bouba and a jagged shape as kiki, only 56% of children with ASD would make this crossmodal correspondence. Noteworthy, compared to neurotypical people, those with ASD pay less attention to social stimuli such as faces or facial configurations (similar in shape to curved figures). It is possible that they may not perceive social stimuli as sufficiently interesting or motivating (Chevallier et al., 2015; Martin et al., 2019), or these stimuli may not be a priority for their attentional system (Chawarska et al., 2010). Given this framework, future studies should expand this research line both from a behavioural and neural perspective. Addressing such specific populations would be particularly relevant because people's well-being and inclusiveness can be fostered with the design of ecological and friendlier environments (Palumbo et al., 2020).

To what extent are the findings of this dissertation generalizable to real-world situations? An ecological approach of preference for curvature also links to how and where we conduct our studies.

[6] Autism Spectrum Disorder.

In general, we investigate the effect through verbal measures. Furthermore, we intentionally conduct our studies in the laboratory to minimize the sort of contextual elements that contribute to shaping experiences in everyday environments (Mastandrea et al., 2009; Tschacher et al., 2012). Even though these approaches have proven fruitful and valuable, they are not free from limitations. On the one hand, verbal measures are subjected to how participants understand the instructions of the task. Participants' judgements may be affected by undesired factors related to expectations, social desirability, and other uncontrolled individual-related variables (Nadal & Vartanian, 2021). On the other hand, we study the experience of stimuli in the laboratory. However, we actually experience such stimuli in real-world situations. These ideas are not against conducting studies with verbal measures in rigorous and controlled environments such as the laboratory. Instead, they propose that future studies also adopt more ecological and comprehensive approaches. Fortunately, this proposal is already underway, and some studies in this line have been made from this project. For example, we plan to estimate the effect of curvature from an implicit perspective (e.g., implicit association tasks, manikin tasks, SRC tasks, etc.) in a meta-analysis. This study will examine the implicit association of curvature and angularity with positive and negative values, respectively. Importantly, we believe that the results could complement those of our meta-analysis using explicit measures (Chuquichambi, Vartanian et al., 2022). In fact, we have already fitted a three-level meta-analysis model with 10 studies, 14 samples of participants, and 23 effect sizes (Bertamini et al., 2016; Chuquichambi, Corradi et al., 2021; Kovic et al., 2010; Larson et al., 2012; Palumbo et al., 2015; Parise & Spence, 2012; Pleyers, 2021; Salgado-Montejo et al., 2016; Stroessner et al., 2020; Velasco et al., 2016). Preliminary results revealed a moderate-to-large implicit association effect of curved and angular stimuli with positive and negative values, respectively ($g = 0.60$, $t = 3.50$, $p = 0.0020$, 95% CI [0.25, 0.96], $k = 23$). Importantly, when we split this general effect, the results revealed a moderate-to-large implicit association effect of curvature with positive values ($g = 0.58$, $t = 2.84$, $p = 0.025$, 95% CI [0.097, 1.06], $k = 8$), but only a small implicit effect of angularity with negative values ($g = 0.28$, $t = 2.32$, $p = 0.054$, 95% CI [-0.0061, 0.57], $k = 8$). However, these last results should be interpreted with caution because some studies did not report the necessary data to calculate effect sizes (only 8 effect sizes from 6 studies were analyzed).

```r
# Get Figure 2.
rl <- lapply(list('RotondaWest.png','BrondbyHaveby.png',
      'PearlQatar.png','PalacioKarlsruhe.png'), png::readPNG)
gl <- lapply(rl, grid::rasterGrob)
do.call(gridExtra::grid.arrange, gl)
```

Figure 2: Examples of cities incorporating aspects of nature (and its features) into architecture and urban planning.

These cities have a radial urban plan and natural structured environments: they facilitate human interactions and impact physical and psychological well-being (Buras, 2019; Roe and McCay, 2021). Left-top: Rotonda West, Florida, USA. Right-top: Brondby Haveby, Copenhagen, Denmark. Left-bottom: The Pearl Island, Doha, Qatar. Right-bottom: Karlsruhe Palace, Karlsruhe, Germany. (Source: Google search).

Recent studies have also examined preference for curvature using physiological measures such as eye-tracking (furniture design; Chuquichambi, Tráwinski et al., 2022), or introducing virtual reality (living environments; Tawil et al., 2021, 2022) and real contexts (paintings in museums; Munar et al., 2023). Such studies demonstrate that this topic remains an active area of inquiry from an applied perspective. Importantly, future studies could also extend this applied interest from architecture (e.g., Vartanian et al., 2013, 2019) to urban planning *(Figure 2)*. This proposal raises from the idea that incorporating aspects of nature into buildings and urban environments may reduce people's physical and psychological distress (Brielmann et al., 2022; Buras, 2019). Our sensory systems are tuned to natural environments and their prevalent features (e.g., fractality, symmetry, curvature, etc.) because of millions of years of evolution. As such, our neurological response to nature and its features seems effortless, efficient, relaxing, and fluent. Therefore, research on aesthetics and the features we are sensitive play a central role in people's well-being in everyday environments, from buildings to cities, and landscapes.

To summarize, personally, I hope that this dissertation has shown that we can investigate preference for curvature from research fields from the humanities to the natural sciences. I also hope that this work further links this topic to the mainstream of empirical aesthetics, neuroaesthetics, and environmental research. When I first read about the curvature effect, I thought it was a weird, but fun idea. The good news is that it remains a weird and fun idea. Therefore, I am sure that we will continue to enjoy our journey investigating one of the essential features that shapes human visual preference.

5. CONCLUSION

Visual contour is a relevant feature in the perception and evaluation of the objects. We prefer objects with curved contours and associate curvature with more positive values than objects with angular contours. This scenario raised the proposal that human preference for visual curvature might be universal. However, even though this is a well-known effect in the scientific literature, preference for curvature is modulated by various contextual and individual difference factors. In this dissertation, we have synthesized the evidence on preference for visual curvature and estimated how universal this preference truly is. Furthermore, we have yielded new empirical evidence that reveals the flexibility of the effect under different conditions.

Specifically, we have demonstrated preference for visual curvature as a reliable and moderate effect, coexisting with substantial heterogeneity variance between studies. Importantly, we have shown that feature interaction, familiarity, and individual differences modulate the effect. Together, our findings have also raised a plausible scenario whereby curvature perceptual sensitivity may be linked to the hedonic valuation of curved contours.

We discuss our findings in light of the upsurge of interest from humanities, environmental science, and neuroscience in preference for visual curvature. We believe that the next frontier in this research line may target the neural underpinnings of the effect with the aim of unraveling the brain mechanisms behind one of the essential features that shapes human visual preference.

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