Another ambiguous expression by Leonardo da Vinci

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Empirical Research

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Another Ambiguous Expression by Leonardo da Vinci

1. Introduction

One of the key features of Leonardo da Vinci (1452–1519)'s Mona Lisa (1503–6) is her ambiguous expression. Soranzo and Newberry (2015) demonstrated that a comparable ambiguity can be observed in La Bella Principessa (1495–6), a portrait of a young girl on vellum thought to be a Leonardo (Kemp, Cotte, Schwan, Strinati, & Biro, 2010). The similarity in the expression forges the connection between the Mona Lisa and La Bella Principessa and supports the attribution of both masterpieces to Leonardo. Figure 1 shows the two portraits: when viewed with the periphery of the eye or from afar, the expressions of both figures look more content than when viewed directly or from close-up.

This paper shows that another comparable ambiguity can be observed in the Head of a Young Woman with Dishevelled Hair (1508, or *La Scapigliata*, Oil on panel; preserved at the Galleria Nazionale, Parma, Italy); an unfinished painting also claimed to be a Leonardo. As is the case for La Bella Principessa, the attribution of the Scapigliata to Leonardo is not unanimously accepted, with art historians such as Jacques Franck attributing it to the Leonardo's pupil Boltraffio (Palmer, 2018). The presence of an ambiguous expression in La Scapigliata, which is similar to the expressions of the Mona Lisa and La Bella Principessa, contributes to the discussion.

The paper is organised as follows: first, the type of ambiguity in Leonardo's portraits is identified and operationalised. The spatial frequency hypothesis advanced by Livingstone (2000) to explain the ambiguous expression in the Mona Lisa is then outlined, together with an account of the specific painting technique used by Leonardo. The experimental session shows that the expression of the Scapigliata is indeed ambiguous. The conclusion argues that the spatial frequency hypothesis is useful to explain the ambiguity observable in Leonardo's paintings, but may not capture the full extent of the phenomenon, for which a phenomenological account might be necessary, as Verstegen (2005) suggested. Specifically, the present study argues that the perceptual belongingness principles advanced by Wertheimer (1923) may need to be considered to fully account for Leonardo's ambiguous expressions.

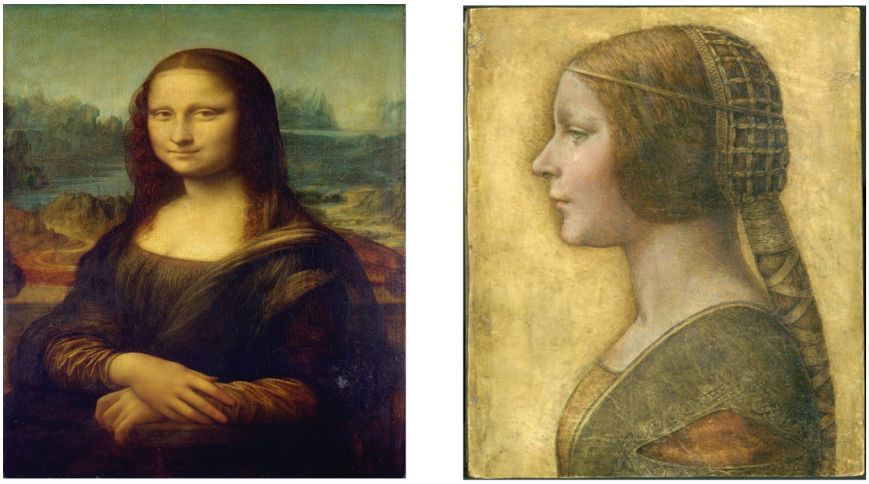

Fig. 1. Mona Lisa and La Bella Principessa. Both portraits exhibit an ambiguous expression.

1.1. Type of ambiguity in Leonardo's work

The Mona Lisa is renowned for her enigmatic smile (Gombrich, 1995; Livingstone & Hubel, 2002). The word 'smile' may lead to the assumption that the ambiguity resides in the happy/sad type of emotion and indeed some authors made this assumption (Kontsevich & Tyler, 2004; Liaci, Fischer, Heinrichs, van Elst, Kornmeier, 2017). However, ambiguity is a multidimensional construct (Muth & Carbon, 2016) as it involves different aspects of the emotional sphere (e.g. confidence/apprehension; bored/interested, etc.). Most importantly, Leonardo's ambiguous expressions may not even pertain to emotions but rather to moods. In his account of Leonardo's ploy of the Mona Lisa, the artist and art historian Giorgio Vasari (1511–1574) reported that Leonardo had musicians who played and sang and clowns who would always make Mona Lisa merry, in order to drive away her melancholy, which is often caused by posing for a painting (Vasari, 1882).[1] Vasari uses words such as *allegra* and *malinconico* (see note 1), meaning merry and melancholic, respectively. These terms refer to an intimate state rather than an external visible expression, a mood rather than an emotion (Beedie, Terry, & Lane, 2005). This nicely matches with Leonardo's concept of *moti mentali* introduced in his Trattato della Pittura (da Vinci, 1632/1817). Leonardo insisted that the goal of the portraitists is to represent the inner thoughts and the transient and dynamic mental states of their models rather than their outward emotions. In addition, from a qualitative investigation (Soranzo & Newberry, 2015), it

[1] "Usovi ancora questa arte, che essendo Mona Lisa bellissima, teneva mentre he la ritraeva, chi sonasse o cantasse, e di continuo buffoni che la facessino stare allegra, per levar via quel malinconico che suol dare spesso la pittura a i ritratti che si fanno" (Vasari, 1882; p. 556).

emerged that the ambiguity depicted in La Bella Principessa is better captured by the contentment/melancholic dimension rather than the happy/sad type of emotion.

The distinction between moods and emotions may seem pedantic but it can have important consequences. For example, Liaci et al. (2017) found that the Mona Lisa 'always' appears happy, contradicting the established description of the portrait as the most celebrated example of ambiguity (Gombrich, 1995; Livingstone, 2000; Livingstone & Hubel, 2002; Mamassian, 2008; Pater, 1917). One of the reasons for this unexpected result might stem from the fact that measurements of an emotion, rather than of a mood, were carried out.[2]

1.2. Definition of ambiguity

To study ambiguity empirically it is necessary to operationalise the term. In this paper, ambiguity is conceived as the difference in the perceived expression under different viewing conditions. In this way, the concept is derived indirectly – as it arises from the comparison between two or more viewing conditions – making it a more reliable and stable measure compared to asking the participants directly whether a figure is ambiguous or not.

1.3. The spatial frequency hypothesis

Scholars from a range of disciplines have debated for centuries the reasons for the ambiguity in the Mona Lisa. An interesting explanation of this ambiguity is advanced by Livingston with what can be named the spatial frequency hypothesis (Livingstone, 2000). The author outlines, "Perhaps it is the difference in her expression carried by high and low spatial frequency ranges […] that helps produce her smile's elusive quality" (p.1299).

The spatial frequency range is defined by the amount of visible detail; high spatial frequencies are associated with fine details, whereas low spatial frequencies relate to coarse aspects of the stimulus (De Valois & De Valois, 1980). In this way, different spatial frequencies convey different information: low spatial frequencies provide information about the global aspects of a stimulus, whilst high spatial frequencies provide information about its details (Goffaux & Rossion, 2006; Sergent, 1994; Shulman & Wilson, 1987).

[2] Another possible reason for the unusual result in Liaci et al.'s study (2017) may lie in the use of a forced choice paradigm between the happy and sad emotional poles. A dichotomous experimental technique might not be sensitive enough to detect a perceptual change in subtle emotional changes. In this regard, Carroll & Russell (1996) argued that forced-choice tasks, where participants choose from predetermined lists of basic emotions, do not allow the observer to engage with deeper emotions; the respondent is not enabled to provide responses that are accurately reflective of their thoughts (see also Yeshurun, Carrasco, & Maloney, 2008).

Empirical evidence in support of the spatial frequency hypothesis has been provided, for both the Mona Lisa and La Bella Principessa. For example, by using a random luminance noise technique to manipulate the spatial frequency of the Mona Lisa, Kontsevich and Tyler (2004) identified the origin of the ambiguity in the region of the mouth. Soranzo and Newberry (2015) found a similar result investigating La Bella Principessa: when the mouth of the princess is masked, the expression does not look as ambiguous. To summarise, according to the spatial frequency hypothesis, Leonardo's ambiguity arises owing to the simultaneous presence of high and low spatial frequencies. The simultaneous presence of overlapping spatial frequencies was obtained by Leonardo through his distinctive painting technique. In both the Mona Lisa and La Bella Principessa, Leonardo made a large use of *sfumato*. From the Italian word for 'vanishing like smoke', in *sfumato* the transitions from bright to dark – or from one colour to another – are subtle, and soften or obscure sharp edges, resulting in an overlaying of multiple translucent layers of paint (Elias & Cotte, 2008). This technique was originally developed by northern European oil painters such as Jan van Eyck (1390–1441), in which a translucent paint is laid over an opaque one. However, Leonardo modified this technique in a unique way.

1.4. Leonardo's unique *sfumato*

Leonardo trained in the workshop of Andrea di Cione, alias Il Verrocchio (1435–1488), where he learned different skills, as well as introduced elements that do not seem to derive directly from Verrocchio's teaching (Ball, 2010). One of these elements is the unique use of *sfumato*. Although this technique was introduced by northern European painters and used by other artists of that era, Leonardo improved and transformed it into a powerful tool for creating atmosphere and depth. In his *Trattato della Pittura*, Leonardo describes *sfumato* as without lines or borders, in the manner of smoke or beyond the focus plane, thus trying to convey the idea of visually indistinguishable passages from one colour to another. Leonardo underlined the importance of making the transition between shadows and light imperceptible:

> "[…] your shadows and lights must be jointed without any sign, as smoke" (da Vinci, 1632/1817, par. 67).

Leonardo was particularly interested in how the eye perceives the details of an image (Argenton et al., 2019). This can be seen in Leonardo's diagram in Manuscript D, f 10v of the *Trattato della Pittura*. In this diagram, Leonardo demonstrated what he coined the 'confusing edge' effect (while Kemp (1977) used the term 'blurred edge effect' to refer to this phenomenon): the eye does not know the ends of any object.

As it can be seen in Figure 2, the margin of the object **cp** is perceived by the upper part of the pupil, **a**, in position **h** on the background object **mn**, whilst the bottom part of the pupil, **b**, will see it in **d**. The radius **rf** will therefore be more detailed from those far away from the central axes. According to Leonardo, paintings should render the impression of three-dimensional relief. This relief is primarily provided by the shadow.

The Scapigliata is a key example of how Leonardo's *sfumato* is different from other '*sfumatos*' and how this technique adds, in some of Leonardo's figures, ambiguity to the expression. Particularly interesting is to compare La Scapigliata with the Head of a Woman with Elaborate Coiffure (1480, black chalk on paper; preserved at the British Museum, London, UK) by Verrocchio. Figure 3 shows La

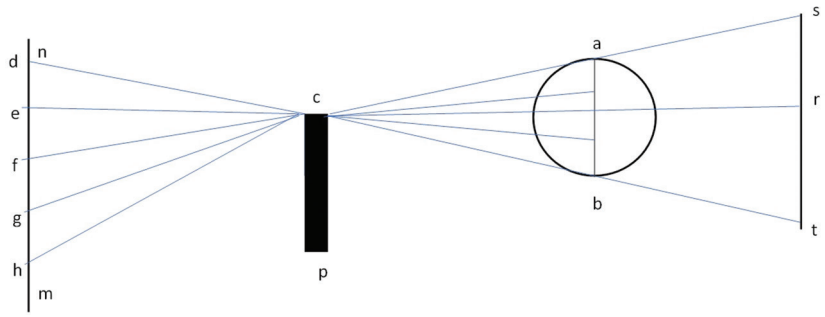

Fig. 2. Leonardo's confusing edge effect.

Fig. 3. (A) Leonardo's head of a Young Woman with Tousled Hair, or *La Scapigliata*, 1508, oil on panel; preserved at the Galleria Nazionale, Parma, Italy. (B) Verrocchio's head of a Woman with Elaborate Coiffure, 1480, black chalk on paper; preserved at the British Museum, London, UK.

Scapigliata (left) and Verrocchio's head (right). The Scapigliata is derived directly from the highly finished Verrocchio's head (Nagel, 1993). The two heads are similar in many aspects, especially in their function as studies in light and shade. In both, the shadow on the left side of the jaw lightens and reinforces the right cheek. The main difference between the two is the use of hatch lines which are visible in Verrocchio's painting but practically imperceptible in Leonardo's. As the art historian Alexander Nagel emphasised, in Verrocchio's drawing the shadow plays a local function within the contours, whilst in Leonardo's shadows are no longer part of the form. This detail might be the key for the understanding of Leonardo's ambiguity.

2. Experiment

The experimental phase of the project tested the perceived expression of Leonardo's Scapigliata and compared it with Verrocchio's Woman with Elaborate Coiffure. For this purpose, participants were requested to rate the level of Contentment of both these artworks from one of the randomly assigned distances (see Soranzo & Newberry, 2016 for details). As outlined in the introduction, a portrait is classified as ambiguous if different ratings are given from different viewing conditions. Therefore, because of the difference in the hatch lines, ratings were expected to change with distance for the Scapigliata but not for Verrocchio's Woman with Elaborate Coiffure.

2.1. Ethics

This project was approved by the Psychology Research Ethics Panel at Sheffield Hallam University (No. ER12646660).

2.2. Method and stimuli

In a mixed measure experimental design, the following variables were systematically manipulated: Drawing (Leonardo's vs. Verrocchio's heads; within subjects) and Viewing Distance (Close: 0.6 m and Far: 6 m; between subjects). These distances have been selected to maximise the effect of distance if it exists; see Soranzo and Newberry (2016). The dependent variable was the Perceived Contentment, which was rated from 1 (no content) to 7 (very content).

While the variable Drawing was measured within subjects, the variable Viewing Distance was measured between subjects. This was to control for the 'experimental subordination' phenomenon (Asch, 1956; Gilchrist, 2020). If the same participants had seen the same portrait from different distances, they might have

adjusted their answers according to what they thought they were expected to respond.

Good-quality, frame-less, exact-sized and foam-backed digital copies of La Scapigliata (24.7 cm in height and 21 cm in width) and the Woman with Elaborate Coiffure (32.5 cm in height and 27.2 cm in width) were wall mounted 1.80 m from the floor in diffused lighting such that the pictures could be approached unimpeded. The portraits were viewed at either 0.6 m (Close condition) or 6 m (Far condition). The sizes of the retinal images of the portraits in degrees of visual angle (height vs. width, respectively) were:

- For Leonardo's head: 22.6° × 19.9° (Close) and 2.3° × 2° (Far);
- For Verrocchio's head: 30.3° × 25.5° (Close) and 3.1° × 2.6° (Far).

2.3. Procedure

The portraits were placed at the corner of an L-shaped corridor so that they could be accessed from two doors. Observers randomly assigned to the Close condition entered the corridor from the closest door whilst observers randomly assigned to the Far condition entered the corridor from the most distant door. They were instructed to stop at a location indicated by a sign on the floor, and rate from 1 to 7 the Perceived Contentment in the expressions of the women in the portraits. Observers could see the portrait from the assigned location only and did not experience any change in the Viewing Distance.

2.4. Data Availability

Dataset and code for analysis are provided as part of the replication package together with an Rmarkdown version of this paper. They are available at: https:// https://osf.io/34zgs/

2.5. Sample size and stopping rule

The procedure 'sequential Bayes factors' (SBF) was followed to determine the sample size. The Bayes factor (*BF*) quantifies the evidence in favour of the experimental hypothesis compared to the null hypothesis. The SBF procedure involves the calculation of subsequent *BFs* after the collection of each new data element, up to the achievement of a *BF* value determined a priori. Jeffreys (1961) suggests continuing the data collection until a *BF* of 10 is reached, as this value is considered 'strong' evidence in favour of the considered hypothesis. The use of the SBF therefore allows flexible sampling plans not strictly dependent on a-priori hypothesised effects. Contrary to frequentist statistics where the use of a similar technique would produce different probability values, Bayesian formalism entails that the decision on whether to terminate data collection is irrelevant for the

assessment of the strength of the evidence (Kruschke, 2013; Kruschke, 2015; Kruschke & Liddell, 2018; Wagenmakers, Gronau, & Vandekerckhove, 2019). Before starting the experiment, data collection was planned to end based on the following 'stopping rules':

(1) An a-priori power analysis was conducted to determine the adequate sample size within each experiment (Maxwell, Kelley, & Rausch, 2008). The minimum effect that would have theoretical meaning in the context of the present study was decided based on the results obtained by Soranzo and Newberry (2015), as a similar procedure was employed in their study. The between-participants and within-participants interaction suggested that 16 participants would be required for each of the between-participants independent variables (suggested power of 0.8, $\alpha = 0.05$ and a medium effect size).
(2) Achievement of a *BF* in favour of one of the hypotheses equal to 10 (as suggested by Jeffreys, 1961).

Sampling stopped after 16 participants per each group of the Viewing Distance variable as the BF_{10} on the difference between the Close and Far conditions of La Scapigliata exceeded 57k.

2.6. Participants

Thirty-two participants took part in this study (age range: 20–51), of which 19 females. Participants were naïve to the purpose of the study and received no remuneration for taking part. They all had normal or corrected-to-normal visual acuity. Written informed consent was obtained from each participant in accordance with the University's ethical procedures.

2.7. Data analysis

Bayesian mixed-effects models were used on content ratings with Portrait and Viewing Distance as independent variables. The random structure of the model included a different intercept for each participant. Linear mixed-effects models enable generalization across both stimuli and participants (Judd, Westfall, & Kenny, 2012). The Bayesian approach was chosen without relying on the Bayes factors for a decision concerning experimental hypothesis (Kruschke & Liddell, 2018; Van der Linden & Chryst, 2017). This approach was chosen as it avoids the statistical peculiarities of null-hypothesis significance testing, for instance, the dependence on predefined sampling plans (Gelman, Carlin, Stern, & Rubin, 1995; McShane, Gal, Gelman, Robert, & Tackett, 2019; Wagenmakers, 2007). In addition, this approach allows conclusions based on a

null effect (Dienes, 2014), which is particularly useful in the context of this project as a null effect of distance is predicted for Verrocchio's portrait.

Models were created in Stan computational framework (Carpenter et al., 2017) accessed with the high-level interface *brms* package 2.10.0 (Bürkner, 2017b, 2017a), in R version 3.6.2 (Team, 2019). As the dependent variable was measured on a 7-point Likert scale, ordinal families were used in the model specification as recommended by Liddell and Kruschke (2018). Specifically, the cumulative function was used with the 'probit' link in the first model, which was then compared with other ordinal models as suggested by Bürkner and Vuorre (2019) (see model comparison section).

To improve convergence and guard against overfitting, the default weakly informative priors were set for the intercept *student_t* (3, 0, 2.5) and fixed effects. For model estimation, four chains with 20,000 iterations and 1,000 warm-ups were used. Convergence was checked via Gelman and Rubin (1992) convergence statistics (Rhat close or equal to 1.0) and by visual inspection of trace plots.

All presented credible intervals are highest density intervals (HDI). A decision rule was formulated based on the HDI and predefined regions of practical equivalence (ROPE) around zero (Kruschke & Liddell, 2018). Model comparison was conducted through the leave-one-out cross-validation (LOOCV, Vehtari, Gelman, & Gabry, 2017).[3] Decisions about predictors being different from zero are based on the relative positions of the high posterior densities (HDPs, Box & Tiao, 1992; Chen, Shao, & Ibrahim, 2000; Hespanhol, Vallio, Costa, & Saragiotto, 2019).

2.8. Results

Figure 4A shows the median and box plot and dispersion of the data. Figure 4B represents the number of times each score has been rated by the participants organised according to the variables Portrait and Viewing Distance.

Table 1 indicates the population-level (fixed) effects of Bayesian linear mixed-effects model for the level of Contentment.

Whilst both Verrocchio's and Leonardo's heads appear similarly content when they are seen from the Close condition, Leonardo's head appears more content from the Far condition whilst the level of Contentment of Verrocchio's head does not increase with distance.

[3] LOOCV provides a score that can be interpreted in the same way as typical information criteria, such as Akaike's information criterion (AIC, Akaike, 1998) or the Watanabe–Akaike information criterion (WAIC, Watanabe & Opper, 2010), in the sense that smaller values indicate better fit. To decide whether a model was substantially better than another, we used the criterion that the LOOIV difference between the two had to be greater than twice its corresponding standard error.

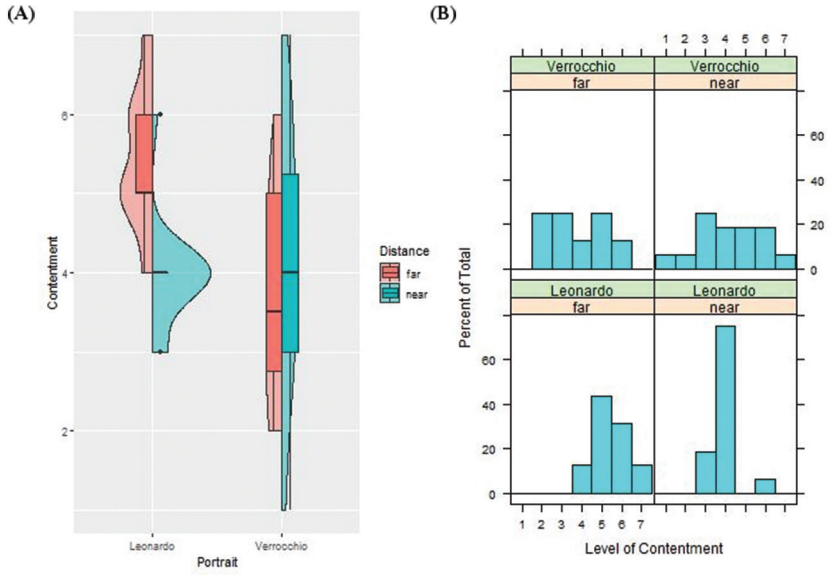

Fig. 4. (A) Split-violin plot of the level of contentment for the Scapigliata to the left (referred as 'Leonardo' and of the Woman with Elaborate Coiffure to the right (referred as 'Verrocchio'). (B) Histogram of the ratings.

Table 1. Population-level effects of Bayesian linear mixed-effects model for Contentment

Effect	Estimate	Est. Err.	l–95%	u-95%
PortraitVerrocchio	1.80	0.44	–2.67	–0.95
Distancenear	–1.62	0.53	–2.70	–0.63
PortraitVerrocchio:Distancenear	2.06	0.59	0.92	3.24

Figure 5 shows the expected probability in the 7-point Likert scale. As can be seen from the figure, whilst in Verrocchio's head the most probable rating is 4 for both distances, the most likely value for Leonardo's head is 4 only for the Close condition but it becomes enhanced to 6 for the Far condition.

2.8.1. Effect of portrait

The point estimate of Portrait indicates that on the latent opinion scale, observers rated Leonardo's head to be 1.8 *sd* more Content than Verrocchio's head (est. error = 0.44). The 95% CI of this parameter is between –2.67 and –0.95. As zero is not included in the CI, we conclude with at least 95% probability that the Scapigliata appears more content.

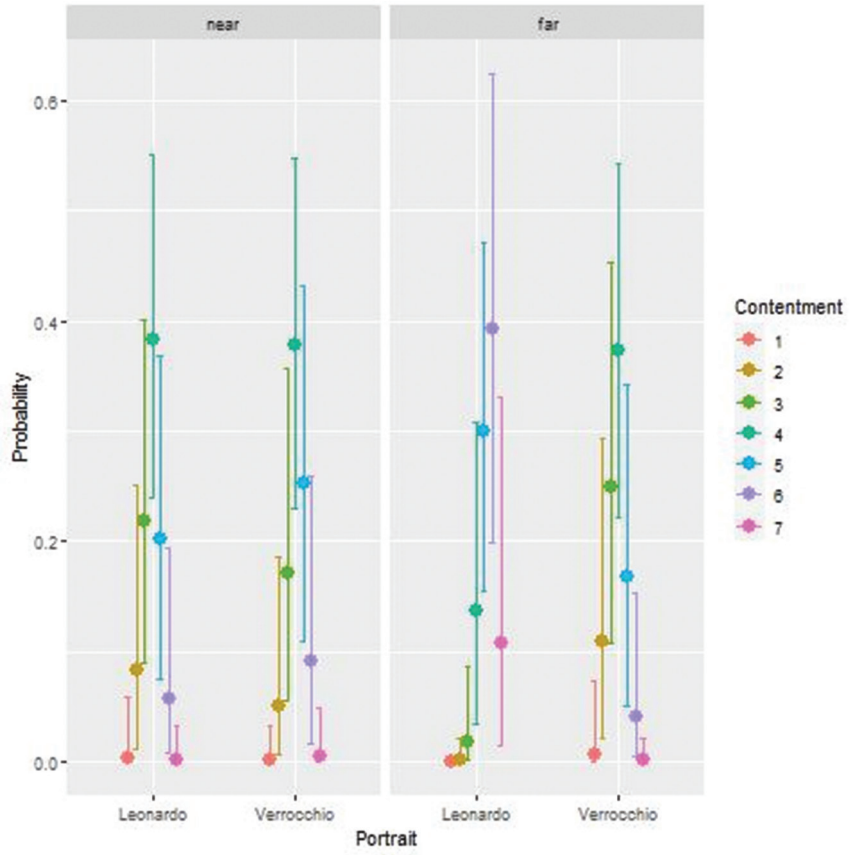

Fig. 5. Plot of the conditional effects of the model.

2.8.2. Effect of viewing distance

The point estimate of Viewing Distance indicates that on the latent opinion scale, when afar the level of Contentment was 1.62 *sd* higher than that from close (est. error = 0.53). The 95% CI of this parameter is between 2.70 and 0.63, and so does not include zero. We conclude that with at least 95% probability that distance affects the perceived level of contentment.

2.8.3. Interaction between portrait and viewing distance

The point estimate of the interaction between Portrait and Viewing Distance shows that on the latent opinion scale the conditional effect of Distance was 2.06 *sd* different between the two heads (est. error 0.59). The 95% CI of this parameter does not include zero [CI (0.92, 3.24)]. To further explore the interaction, the effects of Distance were compared separately for the two heads.

2.9. Post-hoc comparison

A post-hoc comparison was extracted using the *emmeans* package version 1.5.4 (Lenth, 2021). Figure 6 plots the relative positions of the HPDs. As can be seen from the figure, whilst the HPDs of Verrocchio's head include zero (indicating that the level of contentment of the head from the two distances is practically equivalent), the median difference for the two distances of Leonardo's head does not include zero. Table 2 reports the medians and HPDs for the two masterpieces.

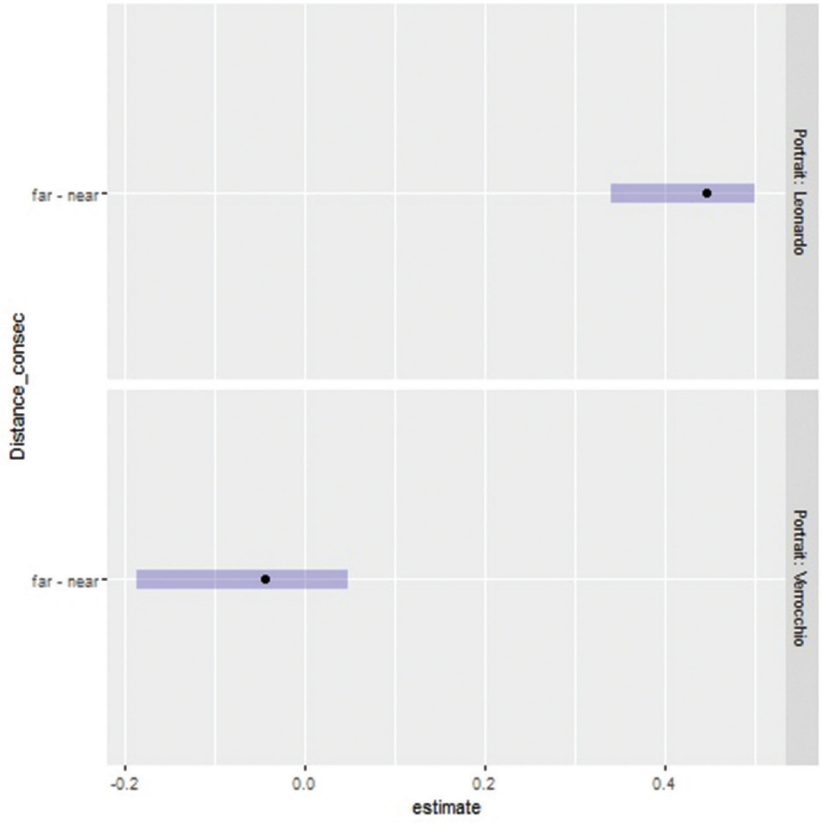

Fig. 6. Difference and HPDs between the two levels of the Distance variable for Leonardo's head (top) and Verrocchio's head (bottom).

Table 2. Estimate of the differences between the two distances

Portrait	estimate	lower.HPD	upper.HPD
Leonardo	0.45	0.34	0.50
Verrocchio	–0.05	–0.19	0.05

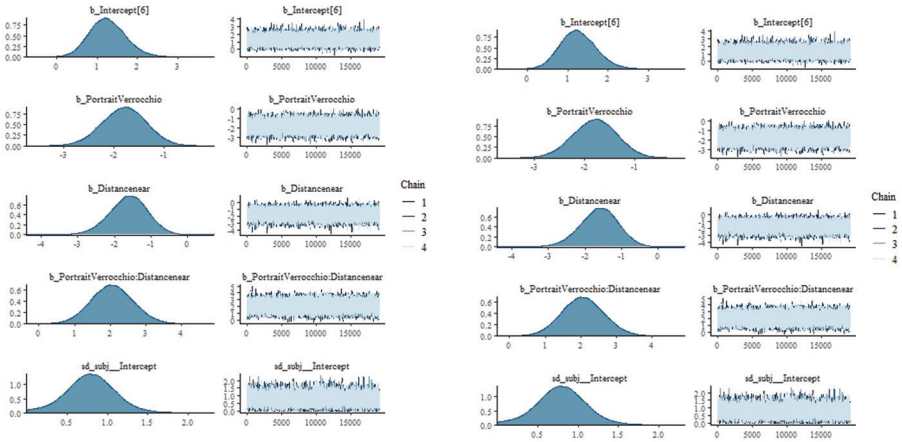

Fig. 7. Model diagnostics.

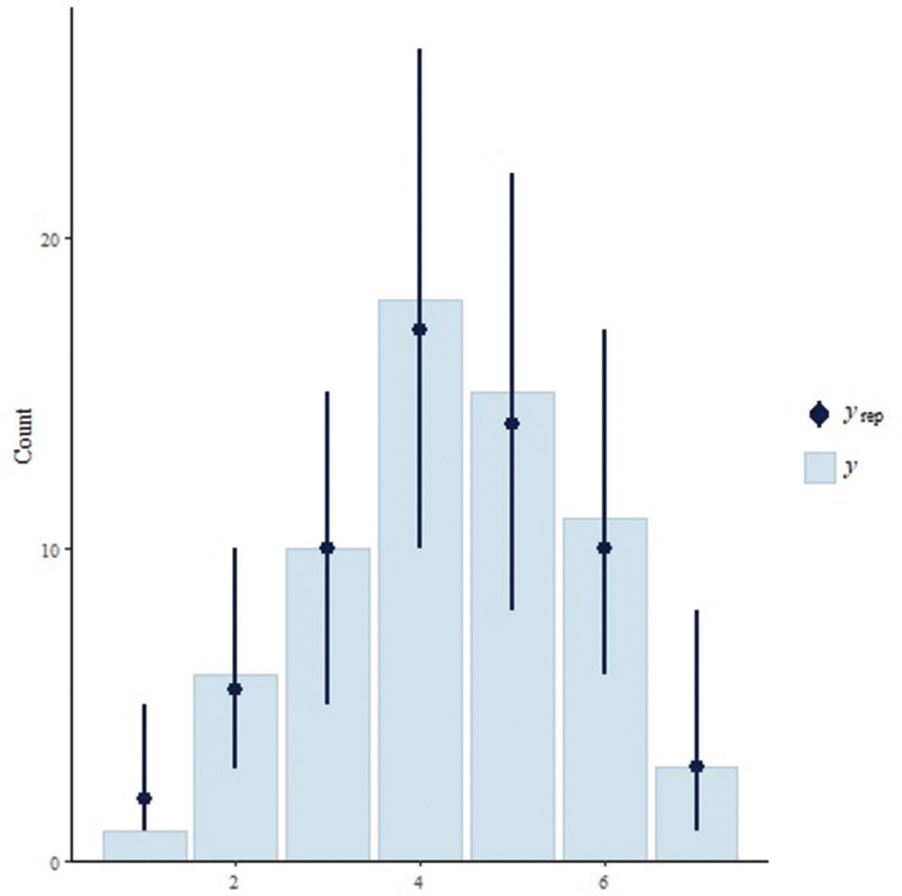

Fig. 8. Posterior prediction check.

2.10. Diagnostics

Diagnostics were checked by ensuring that all *Rhats* were equal (or close) to 1 (Gelman et al., 1995) and by visual inspection of the posterior distribution of all the coefficients and their chain convergence (Figure 7).

2.11. Model evaluation

Figure 8 shows the 95% posterior credible intervals (blue lines) for each of the points in the Likert scale for the interaction between Viewing Distance and Portrait. This shows new *hypothetical data* using those of the posterior distribution as parameters. The actual predicted points are represented by the dark blue dots. Light bars represent the median of recorded ratings. The model seems to work well in predicting the ratings.

2.12. Models comparison

2.12.1. Category-specific effects

A test was conducted to assess whether the effects of the predictors were equal across the Likert scale. For example, the effect of distance may have affected the level of Contentment differently depending on the rating category. To test whether category-specific effects exist, we use the same cumulative function with the 'probit' link as above, but the predictors were encapsulated within the *cs* function.

2.12.2. Unequal variance

A test was conducted to assess whether the variances were the same between the two distance groups by adding an auxiliary regression formula by means of the *if* wrapping function within the *brms* function (Bürkner & Vuorre, 2019). Since the standard deviation of the latent variable is fixed to one for the baseline group, we omitted the intercept from the model.

Model comparison was conducted through the leave-one-out cross-validation (LOOCV, Vehtari et al., 2017). LOOCV provides a score that can be interpreted in the same way as typical information criteria, such as the Akaike information criterion (AIC, Akaike, 1998) or the Watanabe–Akaike information criterion

Table 3. Models comparison

Model	Looic	se
Base	222.8	12.3
Acat model	223.1	16.2
Unequal var	223.1	16.2

(WAIC, Watanabe & Opper, 2010), in the sense that smaller values indicate better fit.

Table 3 shows that the model including category-specific effects was not substantially better than the model without these effects ($elpd\_diff = -0.2$, $se = 6.4$), suggesting that the effects of Distance and Portrait were equal across the Likert scale. Similarly, the parameter estimates from an unequal-variances model suggest that the variances of Distance and Drawings were not substantially different and did not improve the model fit ($elpd\_diff = -0.2$, $se = 6.4$).

3. Discussion

Ambiguity in the Mona Lisa and in La Bella Principessa are well-documented (Gombrich, 1995; Livingstone, 2000; Livingstone & Hubel, 2002; Mamassian, 2008; Pater, 1917; Soranzo & Newberry, 2015). The present work shows that a similar ambiguity can be observed in the Head of a Young Woman with Tousled Hair, or La Scapigliata (Figure 3A), which is another portrait attributed to Leonardo da Vinci (although not unanimously).

As outlined in the introduction, the type of ambiguity in Leonardo's work must be sought in the melancholic-content spectrum, and this ambiguity is believed to be a mood rather than an emotion. The distinction between moods and emotions is nicely outlined by Beedie et al. (2005). I believe that this distinction is important to understand Leonardo's work. Leonardo's intent was of representing the **moti mentali** of his models, their internal turmoil, not their external emotions.

In this project, ambiguity is operationalised as the difference in the perceived expression under different viewing conditions. This way of conceiving ambiguity is useful for experimental purposes as it allows its explicit measurement. To show that the expression of the Scapigliata is ambiguous, the perceived level of contentment was measured from two viewing distances. The portrait was considered ambiguous if the perceived level of contentment was substantially different between the two. In addition, Verrocchio's painting (shown in Figure 3B) was included in the experimental design as a control portrait. The comparison between Leonardo's and Verrocchio's portraits is useful because both these depicted heads are similar in many ways (see Nagel, 1993). The results of this experiment show that the viewing distance affects the perceived level of contentment of Leonardo's portrait only, indicating that La Scapigliata shows an ambiguous expression, whilst Verrocchio's portrait does not. Specifically, whilst from close-up both expressions are perceived to be equivalent in their level of contentment, from afar the level of contentment *increases* only in Leonardo's portrait.

This remarkable effect was probably obtained by Leonardo by means of his unique use of *sfumato*. As a difference from the *sfumato* introduced by the northern European oil painters (and used by Verrocchio), Leonardo refined the technique so that it is almost impossible to distinguish any boundaries in his paintings. This creates atmosphere and depth. Furthermore, as shown in this work, it creates ambiguous expressions.

A scientific explanation of how Leonardo's *sfumato* generates ambiguous expressions is offered by the spatial frequency hypothesis (Livingstone, 2000; Livingstone & Hubel, 2002). With reference to the Mona Lisa, Livingstone & Hubel explain that the smile is "[…] differentially apparent in the different ranges of image detail characteristic of different distances from the center of gaze" (Livingstone & Hubel, 2002; p 85).

It should be noted, however, that Leonardo's *sfumato* leads to a perceptual phenomenon. The neurophysiological reduction of the phenomenon advanced by Livingston might not be sufficient to capture the phenomenology of the effect. In this regard, Verstegen (2005) outlined that a phenomenological account of Leonardo's work would sketch "…a fuller idea than a reductivist account because it is more fundamental, closer to the actual experience" (p. 103). In phenomenological terms, it can be said that Leonardo's *sfumato* creates gradual colour transitions favouring the perception of film colours rather than surface colours (Katz, 1911; Kanizsa, 1954, 1979). Inspired by the seminal work of Katz, Kanizsa examined how the colour appearance of a surface changes according to type of margin. Gradual colour transitions created by *sfumato* favour the perception of 'film' colours rather than 'surface' colours. This led Leonardo to create a work whose tone is more seemingly naturalistic and may be at the core of the phenomenological change in the expression rendered by *sfumato*. The experiment reported here indeed shows a key feature of Leonardo's expressions that seems to be shared among the Mona Lisa, La Bella Principessa and La Scapigliata: the ambiguity is consistently in the same direction. All figures look more content from afar, never from close-up. It can be maintained that by means of *sfumato*, Leonardo overlapped different spatial frequencies, especially around the area of the mouth of the figures, so that the smile is more apparent when the portrait is viewed in low resolution. However, this is because *sfumato* alters the phenomenology of the shadows around the mouth. I argue that the spatial frequency hypothesis accounts for Leonardo's ambiguity only partially: It explains that Leonardo's ambiguity depends on the viewing conditions, but it does not account for its perceptual quality.

To fully capture Leonardo's ambiguity, it can be hypothesised that the principles of perceptual belongingness (Wertheimer, 1923) are involved in the phenomenon. Perceptual belongingness principles refer to the processes responsible for determining how the part–whole structure of experienced objects is derived from the unstructured data in the retinal image (Palmer, Brooks, & Nelson, 2003). In the case of Leonardo's portraits, the absence of hatch lines at the border of the lips might make the adjacent shadow perceptually unstable because it does not clearly belong to any part of the face. Similar to material objects, the perception of shadows is affected by the belongingness principles (Kardos, 1934; Soranzo & Agostini, 2006b, 2006a).

I speculate that when Leonardo's portraits are seen in high resolution (e.g. from close-up), the shadow next to the lips tends to belong to the cheek. The same shadow (or at least part of it) however appears to belong to the lips when seen in low resolution (e.g. from afar). In this latter case, being the shadow placed above the corner of the mouth, it makes the mouth appear to take a 'smiley' upward turn. This is why Leonardo's ambiguity in the Mona Lisa, Bella Principessa and Scapigliata are in the same direction: the shadow next to the lips is above the mouth in all three figures. The unstable belongingness of the shadow can also explain why it is more appropriate to refer to Leonardo's ambiguity as a change in a mood rather than in emotion. The change in the belongingness of the shadow corresponding to the viewing conditions creates subtle changes in the expression, not evident ones. The subtleness of the change results in the ambiguity pertaining to an intimate state, which would be a subjective mood rather than an external emotion. Further research is required to test this hypothesis, and would also need to control for additional differences between the two artworks, such as their different colours.

Abstract

The Mona Lisa (1503–6) is probably the most celebrated example of ambiguous expression in art. Soranzo and Newberry (2015) demonstrated that a similar ambiguity can be perceived also in La Bella Principessa (1495–6), another portrait credited to Leonardo da Vinci (1452–1519) by many. The paper aims to show that an ambiguous expression can be perceived in a further painting attributed (although not unanimously) to Leonardo: The Lady with Dishevelled Hair, or La Scapigliata. An experiment was conducted whereby participants rated on a 7-point Likert scale the perceived level of contentment of La Scapigliata and that of a comparable painting created by Andrea di Cione, alias Il Verrocchio. The two artworks were presented in random order to two groups of participants. One group could see the artworks from Close (0.6m) whilst the other group from Far (6m) from a Close (0.6 m) or Far (6 m) condition. Results show that the change of distance affected the perceived level of contentment of Leonardo's figure but not that of Verrocchio's. Specifically, whilst both artworks received similar ratings of contentment from the close-up condition, La Scapigliata was perceived to be more content from

afar. It is concluded that La Scapigliata exhibits an ambiguous expression, and that this ambiguity is similar to the one observed in the Mona Lisa and La Bella Principessa. This result can be only partially interpreted within the spatial frequency hypothesis advanced by Livingstone (2000) and shows that a phenomenological account of Leonardo's work might be more suited to capture the full extent of the phenomenon. Specifically, it is suggested that the principles of perceptual belongingness (Wertheimer, 1923) may need to be considered to fully capture the extent of the ambiguity depicted by Leonardo.
Keywords: Leonardo, Perceptual Belongingness Principles, Ambiguous Expressions, Aesthetics.

References

Akaike, H. (1998). Information theory and an extension of the maximum likelihood principle. In E. Parzen, K. Tanabe & G. Kitagawa (Eds.), *Selected papers of hirotugu akaike* (pp. 199-213). Springer, New York, NY.

Argenton, L. M., Prest, T., Tiziano, A., Tamara, P., Tonzar, C., & Verstegen, I. (2019). *"Il pittore deve studiare con regola". Arte e psicologia della visione in Leonardo da Vinci con lo sguardo di Alberto Argenton e della scuola di psicologia della gestalt dell'universita di trieste*.

Asch, S. E. (1956). Studies of independence and conformity: I. A minority of one against a unanimous majority. *Psychological Monographs: General and Applied*, *70*(9), 1–70. doi:10.1037/h0093718

Ball, P. (2010). Behind the Mona Lisa's smile. *Nature*, *466*(7307), 694–694.

Beedie, C., Terry, P., & Lane, A. (2005). Distinctions between emotion and mood. *Cognition & Emotion*, *19*(6), 847–878.

Box, G. E. P., & Tiao, G. C. (1992). *Bayesian Inference in Statistical Analysis* (Wiley classics library ed). New Jersey, US: Wiley.

Bürkner, P. C. (2017a). Advanced Bayesian multilevel modeling with the r package brms. *arXiv Preprint arXiv:1705.11123*.

Bürkner, P. C., & (2017b). Brms: An r package for Bayesian multilevel models using Stan. *Journal of Statistical Software*, *80*(1), 1–28.

Bürkner P-C, Vuorre M. (2019). Ordinal Regression Models in Psychology: A Tutorial. *Advances in Methods and Practices in Psychological Science*, 77–101. doi:10.1177/2515245918823199

Carpenter, B., Gelman, A., Hoffman, M. D., Lee, D., Goodrich, B., Betancourt, M., Riddell, A. (2017). Stan: A probabilistic programming language. *Journal of Statistical Software*, *76*(1), 1–32.

Carroll, J., & Russell, J. (1996). Do facial expressions signal specific emotions? Judging emotion from the face in context. *Journal of Personality and Social Psychology*, *70*(2), 205.

Chen, M.-H., Shao, Q.-M., & Ibrahim, J. G. (2000). Computing bayesian credible and HPD intervals. In M.-H. Chen, Q.-M. Shao, & J. G. Ibrahim (Eds.), *Monte Carlo Methods in Bayesian Computation* (pp. 213–235). Springer. doi:10.1007/978-1-4612-1276-8_7

da Vinci, L. (1632/1817). *Trattato della pittura*. Stamp. de Romanis.

De Valois, R., & De Valois, K. (1980). Spatial vision. *Annual Review of Psychology*, *31*(1), 309–341.

Dienes, Z. (2014). Using bayes to get the most out of non-significant results. *Frontiers in Psychology, 5*, doi:10.3389/fpsyg.2014.00781

Elias, M., & Cotte, P. (2008). Multispectral camera and radiative transfer equation used to depict Leonardo's *sfumato* in Mona Lisa. *Applied Optics*, *47*(12), 2146–2154.

Gelman, A., & Rubin, D. B. (1992). Inference from iterative simulation using multiple sequences. *Statistical Science*, *7*(4), 457–472.

Gelman, A., Carlin, J. B., Stern, H. S., & Rubin, D. B. (1995). *Bayesian data analysis*. Boca Raton, Florida, US: Chapman; Hall/CRC.

Gilchrist, A. (2020). The integrity of vision. *Perception*, *49*(10), 999–1004. doi:10.1177/0301006620958372

Goffaux, V., & Rossion, B. (2006). Faces are "spatial"—holistic face perception is supported by low spatial frequencies. *Journal of Experimental Psychology. Human Perception and Performance*, *32*, 1023–1039. doi:10.1037/0096-1523.32.4.1023

Gombrich, E. H. (1995). *The story of art* (Vol. 12). London, UK: Phaidon.

Hespanhol, L., Vallio, C. S., Costa, L. M., & Saragiotto, B. T. (2019). Understanding and interpreting confidence and credible intervals around effect estimates. *Brazilian Journal of Physical Therapy*, *23*(4), 290–301. doi:10.1016/j.bjpt.2018.12.006

Jeffreys, H. (1961). *The theory of probability*. Oxford, UK: Oxford University Press.
Judd, C. M., Westfall, J., & Kenny, D. A. (2012). Treating stimuli as a random factor in social psychology: A new and comprehensive solution to a pervasive but largely ignored problem. *Journal of Personality and Social Psychology*, *103*(1), 54–69. doi:10.1037/a0028347
Kanizsa, G. (1954): Il gradiente marginale come fattore dell'aspetto fenomenico dei colori. *Archivio di Psicologia, Neurologia e Psichiatrica, 15*, 251–264.
Kanizsa, G. (1979): *Organization in vision*: Essays on gestalt perception. New York, NY: Praeger.
Kardos, L. (1934). Ding und schatten. Eine experimentelle untersuchung über die grundlagen des farbensehens. *Zeitschrift für Psychologie Und Physiologie Der Sinnesorgane. Abt. 1. Zeitschrift Für Psychologie*.
Katz, D. (1911). Die Erscheinungsweisen der Farben und ihre Beeinflussung durch die individuelle Erfahrung. *Zeitschrift für Psychologie, 7*(1). JA Barth.
Kemp, M. J. (1977). Leonardo and the visual pyramid. *Journal of the Warburg and Courtauld Institutes*, (*40,*) 128–149.
Kemp, M. J., Cotte, P., Schwan, E., Strinati, C., & Biro, P. P. (2010). *La Bella Principessa: The Story of the New Masterpiece by Leonardo da Vinci*. London, UK: Hodder & Stoughton.
Kontsevich, L. L., & Tyler, C. W. (2004). What makes Mona Lisa smile? *Vision Research*, *44*(13), 1493–1498.
Kruschke, J. K. (2013). Bayesian estimation supersedes the t test. *Journal of Experimental Psychology: General*, *142*(2), 573–603. doi:10.1037/a0029146
Kruschke, J. (2015). *Doing bayesian data analysis: A tutorial with R, JAGS, and Stan*. Elsevier Science. Amsterdam, Netherlands. ISBN: 978-0-12-405916-0
Kruschke, J. K., & Liddell, T. M. (2018). Bayesian data analysis for newcomers. *Psychonomic Bulletin & Review*, *25*(1), 155–177. https://doi.org/10.3758/s13423-017-1272-1
Lenth, R.V. (2021). *Emmeans: Estimated Marginal Means, aka least-squares means* [Manual] url: https://CRAN.R-project.org/package=emmeans
Liaci, E., Fischer, A., Heinrichs, M., van Elst, L. T., & Kornmeier, J. (2017). Mona Lisa is always happy–and only sometimes sad. *Scientific Reports*, *7*(1), 1–10.
Liddell, T. M., & Kruschke, J. K. (2018). Analyzing ordinal data with metric models: What could possibly go wrong? *Journal of Experimental Social Psychology*, *79*, 328–348.
Livingstone, M. (2000). Is it warm? Is it real? Or just low spatial frequency? *Science*, *290*(5495), 1299–1299.
Livingstone, M., & Hubel, D. (2002). *Vision and Art: The Biology of Seeing* (Vol. 2). New York, NY: Harry N. Abrams.
Mamassian, P. (2008). Ambiguities and conventions in the perception of visual art. *Vision Research*, *48*(20), 2143–2153.
Maxwell, S. E., Kelley, K., & Rausch, J. R. (2008). Sample size planning for statistical power and accuracy in parameter estimation. *Annual Review of Psychology*, *59*, 537–563.
McShane, B. B., Gal, D., Gelman, A., Robert, C., & Tackett, J. L. (2019). Abandon statistical significance. *The American Statistician*, *73*(Supp1.), 235–245.
Muth, C., & Carbon, C.-C. (2016). SeIns: Semantic instability in art. *Art & Perception*, *4*(1–2), 145–184.
Nagel, A. (1993). Leonardo and *sfumato*. *RES: Anthropology and Aesthetics*, *24*(1), 7–20.
Palmer, A. L. (2018). *Leonardo da Vinci: A reference guide to his life and works*. Lanham, Maryland, US: Rowman & Littlefield.
Palmer, S. E., Brooks, J. L., & Nelson, R. (2003). When does grouping happen? *Acta Psychologica*, *114*(3), 311–330.
Pater, W. (1917). *La renaissance*. Paris: France Library Payot.
Sergent, J. (1994). Brain-imaging studies of cognitive functions. *Trends in Neurosciences*, *17*(6), 221–227.
Shulman, G. L., & Wilson, J. (1987). Spatial frequency and selective attention to local and global information. *Perception*, *16*(1), 89–101.
Soranzo, A., & Agostini, T. (2006a). Does perceptual belongingness affect lightness constancy? *Perception*, *35*(2), 185–192. doi:10.1068/p5342
Soranzo, A., & Agostini, T. (2006b). Photometric, geometric, and perceptual factors in illumination-independent lightness constancy. *Perception & Psychophysics*, *68*(1), 102–113.
Soranzo, A., & Newberry, M. (2015). The uncatchable smile in Leonardo da Vinci's la Bella Principessa portrait. *Vision Research*, *113*, 78–86.

Soranzo, A., & Newberry, M. (2016). Investigating the 'Uncatchable Smile' in Leonardo da Vinci's la Bella Principessa: A comparison with the Mona Lisa and Pollaiuolo's portrait of a girl. *JoVE (Journal of Visualized Experiments)*, *116*, e54248.

Team, R. C. (2019). 2020. *R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria*. https://www.r-project.org/.

Van der Linden, S., & Chryst, B. (2017). No need for Bayes factors: A fully Bayesian evidence synthesis. *Frontiers in Applied Mathematics and Statistics*, *3*, 12.

Vasari, G. (1882). *Le vite de più eccellenti pittori, scultori ed architettori* (Vol. 8). Florence, Italy: GC Sansoni.

Vehtari, A., Gelman, A., & Gabry, J. (2017). Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. *Statistics and Computing*, *27*(5), 1413–1432.

Verstegen, I. (2005). Mona Lisa's smile: The place of experimental phenomenology within Gestalt Theory. *Gestalt Theory, 27*(2), 91–106.

Wagenmakers, E.-J. (2007). A practical solution to the pervasive problems of p values. *Psychonomic Bulletin & Review*, *14*(5), 779–804.

Wagenmakers, E.-J., Gronau, Q. F., & Vandekerckhove, J. (2019). *Five Bayesian Intuitions for the Stopping Rule Principle* [Preprint]. PsyArXiv. doi:10.31234/osf.io/5ntkd

Watanabe, S., & Opper, M. (2010). Asymptotic equivalence of bayes cross validation and widely applicable information criterion in singular learning theory. *Journal of Machine Learning Research*, *11*(12), 3571–3594.

Wertheimer, M. (1923). Untersuchungen zur Lehre von der Gestalt II [Laws of organization in perceptual forms]. Psychologische Forschung, 4, 301–350. Translation published in Ellis, W. (ed.) (1938): *A Source Book of Gestalt Psychology*, 71-88. London: Routledge & Kegan Paul.

Yeshurun, Y., Carrasco, M., & Maloney, L. T. (2008). Bias and sensitivity in two-interval forced choice procedures: Tests of the difference model. *Vision Research*, *48*(17), 1837–1851.

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