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The Uncatchable Smile in Leonardo da Vinci's La Bella Principessa Portrait

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Abstract

A portrait of uncertain origin recently came to light which, after extensive research and examination, was shown to be that rarest of things: a newly discovered Leonardo da Vinci painting entitled *La Bella Principessa*. This research presents a new illusion which is similar to that identified in the *Mona Lisa;* La Bella Principessa's mouth appears to change slant depending on both the viewing distance and the level of blur applied to a digital version of the portrait. Through a series of psychophysics experiments, it was found that a perceived change in the slant of the La Bella Principessa's mouth influences her expression of contentment thus generating an illusion that we have coined the "uncatchable smile". The elusive quality of the Mona Lisa's smile has been previously reported (Livingstone, 2000) and so the existence of a similar illusion in a portrait painted prior to the Mona Lisa becomes more interesting. The question remains whether Leonardo da Vinci intended this illusion. In any case, it can be argued that the ambiguity created adds to the portrait's allure.

1. Introduction

In 1998 a little known painting catalogued as a 19th century imitation of an Italian Renaissance prototype by an unnamed German Romantic artist was sold for a modest sum in a New York gallery. Later, it was sold to a buyer who suspected that the picture's origin was more prestigious than originally thought (Grann, 2010). Following examination by experts and extensive research by the Oxford art historian Martin Kemp, the portrait (see Figure 1) was held to be a once in a lifetime discovery as it was attributed to Leonardo da Vinci (Kemp & Cotte, 2010).

Figure 1. La Bella Principessa's portrait. Leonardo da Vinci (1495-6).

Further evidence supporting the provenance of the picture and identification of La Bella Principessa came to light in 2011 (Silverman, 2012) which showed that the portrait had been removed from the Warsaw Sforziad, a hand illuminated book associated with the family of Ludovico Sforza, the ruler of Milan in the 1490's and patron of Leonardo (Kemp, 2011). La Bella Principessa was identified as Bianca, the illegitimate daughter of Ludovico who at around 13 years of age was to be married to a commander of the Duke's Milanese forces. The portrait was commissioned by the Duke in honour of the celebration of her marriage in 1496, and Leonardo worked in the employ of the Duke of Milan for many years and painted other portraits associated with his family and court as can be seen in Kemp's (2011) chronology. The picture, showing a young girl in her early adolescence, was executed on vellum using pen ink and a combination of coloured chalk (Kemp & Cotte, 2010). The pen and brown ink combine with the underlying yellow vellum background to create a mellow range of colours and skin tones. The girl's dress and hairstyle indicate that she was a member of the court of Milan during the late fifteenth century. Her

expression shown in profile is ambiguous and has been described as "subtle to an inexpressible degree" (Kemp & Cotte, 2010; p. 26).

The 'uncatchable' smile

In La Bella Principessa's portrait, the princess's smile can be seen to have an enigmatic quality about it, described by Kemp as "poised but pensive, the look of someone growing up too fast" (O'Neil, 2012, p.1). The expression of the young princess is difficult to interpret, perhaps reflecting Leonardo da Vinci's maxim in his *A Treatise on Painting* (translated into English by Rigaud & Brown, 1835) that a portrait should reveal the "mental motions" (p.48). Because of the considerable changes which were about to take place in her life, da Vinci would certainly have understood the complexities of the young girl's situation and sensed any tension between the passing innocence of childhood and the destiny of courtly duties, marriage and child bearing (Kemp & Cotte, 2010).

In scrutinizing the portrait, we noticed that La Bella Principessa's facial expression appears to change when she is viewed from different distances. Specifically, when she is viewed from close-up the mouth appears to have a downwards slant, making her look melancholic, unhappy and hostile, but when viewed from further away, her mouth appears to take an upward, smile-like appearance making her appear happy and cheerful. In addition, a similar effect can be observed when the portrait is viewed with different levels of blur (i.e. different spatial frequencies**)**. Specifically, when a blurred image of the portrait is viewed (in low spatial frequency) the princess appears happier than when a non-blurred image is viewed. As the smile disappears as soon as the viewer tries to 'catch it' we have named this visual illusion the "uncatchable smile".

This effect is similar, and perhaps stronger, to that described by the Harvard scientist Margaret Livingstone (2000; 2002) in her account of the Mona Lisa's smile. In this, the author provides a basis for the enigmatic nature of the smile by pointing out that "Perhaps it is the difference in her [the Mona Lisa's] expression carried by high and low spatial frequency ranges […] that helps produce her smile's elusive quality" (Livingstone, 2000; p. 1299).

Illusion effects in art are not new (the interested reader can find a comprehensive catalogue in Gregory & Gombrich, 1973), and the concept of spatial

frequency-dependent facial expression is supported by a wide understanding of how the human visual system is particularly sensitive to seeing and interpreting the subtleties of facial expression (Ekman & Friesen, 1975; Latto, 2002).

Schyns and Oliva (1999) showed that, besides other characteristics, the manipulation of blur influences the perception of facial expression. Furthermore, authors have shown that facial expressions can be read more accurately in low spatial frequency than high spatial frequency (i.e. blurred vs. non-blurred conditions). Similarly, Kontsevich and Tyler (2004) showed that the perception of the Mona Lisa's emotional state along the sad/happy dimension changes when spatial noise is added to the image. In addition, the authors found that the effect of spatial noise on the perceived emotional state of the Mona Lisa is mainly located around the corners of her mouth rather than around her eyes or other facial regions. By the same token, Bohrn, Carbon and Hutzler (2010) have demonstrated how the viewing direction (foveal vs. peripheral) can influence the perception of the Mona Lisa's smile. By adopting saccade-contingent display-change technique that allowed altering the expression of faces depending on the beholder's gaze position, the authors found that the impression of a smile in the Mona Lisa is more prominent when viewed peripherally.

The aim of this research was to investigate the uncatchable smile illusion[1].

2. Qualitative investigation

The first stage of the research involved identification of the psychological dimension to be investigated. Four participants were asked to describe La Bella Principessa's facial expression from different distances. They were shown the portrait in the centre of an A1 paper pad resting on an easel in a naturally day lit room and were asked "How would you describe the lady's expression and do you notice any differences in her expression as you move closer or further away from the portrait"? A Grounded Theory analysis (Glaser, 1992; Glaser & Strauss, 1967; Strauss & Corbin, 1990; 1997) of the descriptions was then conducted and it was found that the most common words used to describe La Bella Principessa's expression were 'smiling', 'happiness' and 'contentment', and changes to her

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[1] The work was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) and informed consent was obtained for the experimentation.

expression as "she looks less content as I move closer" or "she looks more content as I move further away". These qualitative findings which suggest that perception of contentment may be related to distance informed the formulation of the following hypotheses:

> 1. The viewer's distance from La Bella Principessa's portrait will influence their perception of her facial expression and a similar effect will be observed for the Mona Lisa's expression. Specifically, the ratings of contentment will be higher when the portraits are viewed from further away.
>
> 2. The portrait's level of blur will influence the Perceived Contentment of La Bella Principessa and the Mona Lisa. Specifically, presenting digital versions of the portraits with an increased level of blur will lead to an increase in the viewer's perception of contentment.
>
> 3. The uncatchable smile illusion is mainly attributable to the mouth area of La Bella Principessa's portrait.
>
> 4. The perceived slant of La Bella Principessa's mouth will change when the distance of the portrait is manipulated. Specifically, the corner of the mouth will appear to take an upward turn when distance is increased.
>
> 5. The perceived slant of La Bella Principessa's mouth will change when a digital version of the portrait is presented with different levels of blur. Specifically, the corner of the mouth will appear to take an upward turn when the level of blur is increased.

Five experiments were conducted to test these hypotheses.
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3. Experiment 1: On viewing distance

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The first experiment was designed to test Hypothesis 1, that the viewer's distance from La Bella Principessa's portrait would influence their perception of her facial expression and that a similar effect would be observed for the Mona Lisa's expression. Specifically, it was hypothesised that ratings of contentment would be higher when the portraits were viewed from further away. To test whether this effect is specific to La Bella Principessa's and Mona Lisa's portraits or whether it is general to all portraits of da Vinci's era, the control portrait shown in Figure 2 was used. This is the *Portrait of a Girl* painted around 1470 by Piero del Pollaiuolo. This was chosen as a suitable control for La Bella Principessa as the portrait is from the same period and there are similarities of size, presentation and appearance in the subject matter.

Figure 2: Portrait of a Girl. Piero del Pollaiuolo (1470).

Consistent with the findings from the qualitative phase of this study, observers were asked to assess the Perceived Contentment of the women in the portraits from two viewing positions. A between-subjects experiment was conducted which had two independent variables: 1) Portrait (with three levels: Bella Principessa, Mona Lisa, and Pollaiuolo's Portrait of a Girl); and 2) Viewing Distance (with two levels: Close vs. Far). The dependent variable was Perceived Contentment.

3.1. Method
3.1.1. Observers

60 observers took part in experiment 1; 10 in each of the six conditions. All had normal or corrected-to-normal acuity and were naïve with regard to the experimental design. Observers were not familiar with either La Bella Principessa or Pollaiuolo's Portrait of a Girl. Furthermore, observers reported that they hadn't seen the Mona Lisa's portrait for one year or more.

3.1.2. Apparatus and stimuli

Good quality, frameless and exact sized foam backed digital copies of La Bella Principessa (33.2 cm in height x 23.8 cm in width), Mona Lisa (77 cm x 53 cm), and Pollaiuolo's Portrait of a Girl (45.5 cm x 32.7 cm) were wall mounted 1.80 meters from the floor in diffused lighting such that the pictures could be approached unimpeded. The portraits were viewed at either 0.5 meters (Close condition) or 8 metres (Far condition) as indicated in Figure 3. The sizes of the retinal images of the portraits in degrees of visual angle (height vs. width, respectively) were:
- For La Bella Principessa: 36.8 x 26.8 deg. (Close) and 2.4 x 1.7 deg. (Far);
- For the Mona Lisa: 75.2 x 55.8 deg. (Close) and 5.5 x 3.8 deg. (Far);
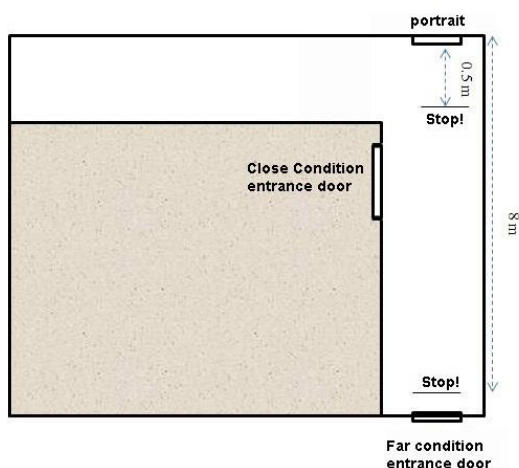- For Pollaiuolo's Portrait of a Girl: 48.9 x 36.2 deg. (Close) and 3.3 x 2.3 deg. (Far).

Figure 3: Sketch of experiment 1. In the Close condition observers entered the corridor from the closest door. In the Far condition observers entered the corridor from the most distant door.

3.1.3. 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.

3.2. Results

A Kolmogorov-Smirnov test for the normality of the raw data showed no significant deviation from normality. A two-way between subjects ANOVA revealed a significant effect of Portrait [$F_{(2,54)}$= 16.67 ; $p. < 0.01$; $\eta p^2 = 0.38$] and of Viewing Distance [$F_{(1,54)}$= 26.88; $p. < 0.01$); $\eta p^2 = 0.33$]. The interaction between the two variables was also statistically significant ($F_{(2,54)}$= 9.7; $p. < 0.01$; $\eta p^2 = 0.26$).

A post hoc analysis revealed a significant difference between both La Bella Principessa vs Pollaiuolo's Portrait of a Girl ($p. < 0.01$) and between the Mona Lisa vs Pollaiuolo's Portrait of a Girl ($p. < 0.01$). However, the difference between La Bella Principessa and the Mona Lisa was not statistically significant ($p. = 0.083$).
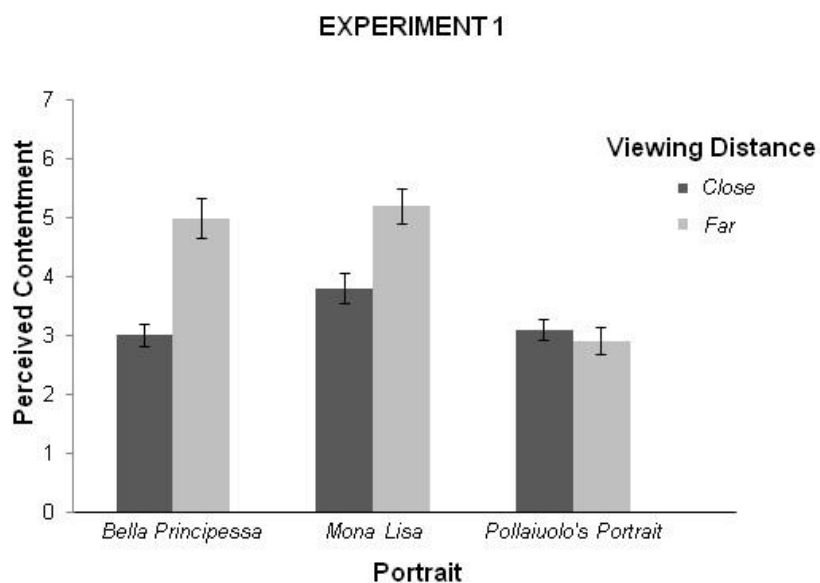

Figure 4: Results of experiment 1. The graph shows that when La Bella Principessa and the Mona Lisa are observed from close-up, their Perceived Contentment is lower than when they are viewed

from distance, whereas there was no significant effect for Pollaiuolo's Portrait of a Girl. Standard errors are indicated by the lines on top of the bars.

As can be seen from Figure 4, the results of experiment 1 support Hypothesis 1 that there is an illusory effect in La Bella Principessa's portrait which is related to distance; when the portrait is observed from close-up her expression appears less content than when it is viewed from a distance. A similar effect was observed for the Mona Lisa whereas there was no significant effect for Pollaiuolo's Portrait of a Girl. This suggests that the effect of distance is not general to all portraits of da Vinci's era.

4. Experiment 2: On Blur Level

The second experiment tested Hypothesis 2, that the portraits' level of blur would influence the Perceived Contentment of La Bella Principessa and the Mona Lisa. Specifically, it was hypothesised that presenting digital versions of the portraits with an increased level of blur would lead to an increase in the viewer's perception of contentment. For this purpose, a series of digital versions of the portrait with progressively increasing levels of Gaussian blur were used. To test whether this effect is specific to La Bella Principessa's and the Mona Lisa's portraits the same control portrait shown in Figure 2 was used.

Experiment 2 was a repeated-measures design with two independent variables: 1) Portrait (with three levels: La Bella Principessa, the Mona Lisa, and Pollaiuolo's Portrait of a Girl); and 2) Level of Blur (with 8 levels of increasing blur). The dependent variable was Perceived Contentment. It was hypothesised that the level of blur would influence the Perceived Contentment in La Bella Principessa and the Mona Lisa but not in Pollaiuolo's Portrait of a Girl.

4.1. Methods
4.1.1 Observers
10 Observers took part in experiment 2. All had normal or corrected-to-normal acuity and were naïve with regard to the experimental design. None of them had participated in experiment 1 and they were not familiar with La Bella Principessa or

Pollaiuolo's Portrait of a Girl. Furthermore, observers reported that they hadn't seen The Mona Lisa's portrait for one year or more.

4.1.2. Apparatus and stimuli

Digital copies of the portraits were displayed on a 22" (20" viewable) CRT monitor set at a resolution of 1280 x 1024 connected to a Lenovo Intel computer. The creation of a set of digital images presented with different levels of blur was undertaken using Adobe Photoshop Gaussian blur. The blurring process used is essentially a convolution kernel of the pixel spreading type in which pixels take contributions from their surrounding pixels, while de-emphasising contributions from the centre (see Setlur & Gooch, 2004).The Gaussian Blur formula is as follows:

$$G(x,y) = \frac{1}{2\pi} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

where *x* and *y* are the distances from the central pixel, and *σ* is the standard deviation of the Gaussian distribution. By applying this formula to the image, it produces a new image whose contours are concentric circles with a Gaussian distribution from the central pixel. Each pixel's new value is a weighted average between its original value and the value of the pixels which surround it by a given distance. The original value receives the highest weight compared to the surrounding pixels whose weight decreases proportionally with their distance.

In the experiment, blur level was increased in steps of 1 pixel over the range 0 - 7. Each pixel's new value therefore resulted from a weighted average between its original value and the value of the pixels whose distance varied from 0 (non-blurred image) to 7 pixels according to the experimental condition. Thus, eight versions of La Bella Principessa, the Mona Lisa, and Pollaiuolo's Portrait of a Girl were created and mini versions of these can be seen in Figure 5.

Figure 5: Stimuli for experiment 2. Eight digital versions of La Bella Principessa, the Mona Lisa, and Pollaiuolo's Portrait of a Girl were used with step changes in blur level of 1 pixel over the range 0 – 7.

4.1.3. Procedure

Software was developed to display the images in random order on the CRT monitor and to record observers' answers. Observers viewed the stimuli in a well illuminated room at a distance of 50 cm from the monitor. They were instructed to rate the Perceived Contentment in the expression of La Bella Principessa, the Mona Lisa, and Pollaiuolo's Portrait of a Girl from 1 to 7, and entered their ratings using a keyboard with the results being recorded by pressing the spacebar. To eliminate any influences from the previous images affecting observer ratings of the new ones, a random noise mask was presented for 1 second prior to the next image being shown. Each image remained on the screen for as long as the observer desired and the entire session lasted approximately 30 minutes.

4.2. Results

A Kolmogorov-Smirnov test for the normality of the raw data showed no significant deviation from normality. A two-way repeated measures ANOVA revealed a significant effect of both the Portrait variable [$F_{(2,18)}$ = 7.31; $p.$ < 0.01; ηp^2 = 0.45; and the Level of Blur variable $F_{(7,63)}$ = 14.85; $p.$ < 0.01; ηp^2 = 0.62]. The interaction between the two variables was also statistically significant [$F_{(14,126)}$ = 3.60; $p.$ < 0.01; ηp^2 = 0.29)].

Follow-up polynomial contrasts indicated a significant linear effect with Perceived Contentment increasing with the Level of Blur of both La Bella Principessa's portrait [$F_{(1,9)}$ = 28.55; $p.$ < 0.01; ηp^2 = 0.76)], and of the Mona Lisa [$F_{(1,9)}$ = 27.67; $p.$ < 0.01; ηp^2 = 0.75] . Conversely, the linear trend between Level of

Blur and Perceived Contentment of Pollaiuolo's Portrait of a Girl was not significant (*p.* = 0.87).
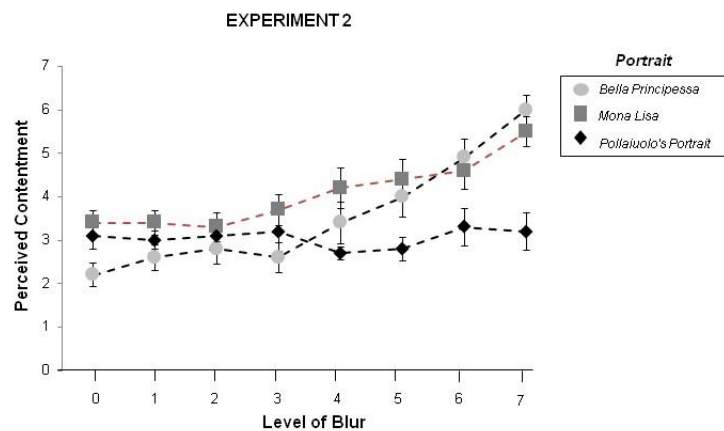

Figure 6: Results of experiment 2. The graph shows that the Level of Blur affected Perceived Contentment of La Bella Principessa and the Mona Lisa but not the Perceived Contentment of Pollaiuolo's Portrait of a Girl. Dotted lines favour the view of the trend. Bars indicate standard errors.

As can be seen from Figure 6, the results of experiment 2 support Hypothesis 2 which was that there would be an illusory effect in La Bella Principessa's portrait which is related to blur. In particular, results showed a linear trend in the relationship between Level of Blur and Perceived Contentment in La Bella Principessa's and Mona Lisa's portraits but this relationship was not present in Pollaiuolo's Portrait of a Girl. This suggests that the effect of blur is not general to all portraits of da Vinci's era.

5. Experiment 3: On establishing the source of the illusory effect

The third experiment tested Hypothesis 3, that the uncatchable smile illusion would be mainly attributable to the mouth area of La Bella Principessa' portrait. For this purpose, digital versions of La Bella Principessa were used in which her mouth, or visible eye, or both, were masked by a black rectangle.

A repeated-measures experiment was conducted which had two independent variables: 1) Level of Blur (with 8 levels); and 2) Mask Position (with 4 levels: No mask, Mouth mask, Eye mask, or both Mouth and Eye masks). The dependent variable was the Perceived Contentment of La Bella Principessa.

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5.1. Methods

5.1.1. Observers

    10 observers participated in experiment 3. All had normal or corrected-to-normal acuity and were naïve with regard to the experimental design. None of them had participated in the previous experiments and they were not familiar with La Bella Principessa's portrait.

5.1.2 Apparatus and stimuli

    The apparatus were the same as those used in experiment 2 where digital images presented with different levels of Gaussian blur were created.

    Using the same eight versions of La Bella Principessa's portrait used previously in experiment 2, three more different sets of masked images were created, for a total of 4 set of images. In the first of these there was no mask; in the second the mouth was masked; in the third the visible eye of La Principessa was masked; and in the fourth both the eye and the mouth were masked. The mask itself was not blurred and its size was 0.3 x 0.6 cm.

    A control set of images was also created without the mask so that overall 32 digital images were generated with differing levels of blur and masking. Figure 7 shows a mini-version of the stimuli used in this experiment for a Blur Level of 0.
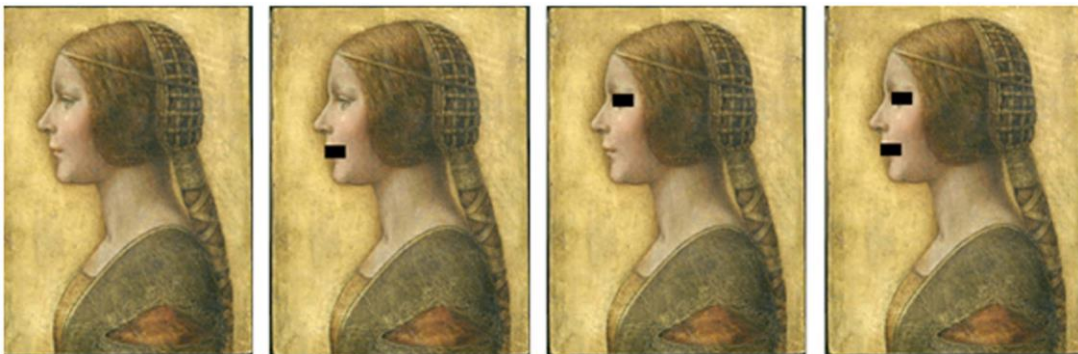

Figure 7: Example of stimuli for experiment 3. The four levels of the Mask variable (Blur Level - 0).

5.1.3. Procedure

    The procedure was the same as for experiment 2. The images were presented in random order on the CRT monitor and the observers viewed the stimuli in a well illuminated room at a distance of 50 cm from the monitor. They were instructed to

rate from 1 to 7 the Perceived Contentment in La Bella Principessa's expression. Observers input their rating using a keyboard which was then recorded by pressing the spacebar. As in experiment 2, following this, a random noise mask was presented on screen for 1 second prior to the next image being presented. Each image remained on the screen for as long as the observer desired and the whole session lasted approximately 25 minutes.

5.2. Results

A Kolmogorov-Smirnov test for the normality of the raw data showed no significant deviation from normality. A two-way repeated measures ANOVA revealed a significant effect of the Level of Blur variable [$F_{(7,63)}$ = 20.8; *p.* < 0.01; ηp^2 = 0.70]; but not the Mask variable (p = 0.13]. However, the interaction between the two variables was statistically significant [$F_{(21,189)}$ = 5.63; *p.* < 0.01; ηp^2 = 0.39)].

Follow-up polynomial contrasts indicated a significant linear effect with Perceived Contentment increasing with the Level of Blur of both the No mask [$F_{(1,9)}$ = 32.46; *p.* < 0.01; ηp^2 = 0.78)] and Eye mask [$F_{(1,9)}$ = 24.01; *p.* < 0.01; ηp^2 = 0.73 Conversely, the linear trend between Level of Blur and Perceived Contentment of both Mouth and both Mouth and Eye masks were not significant ($p.$ = 0.06 and $p.$ = 0.11; respectively).
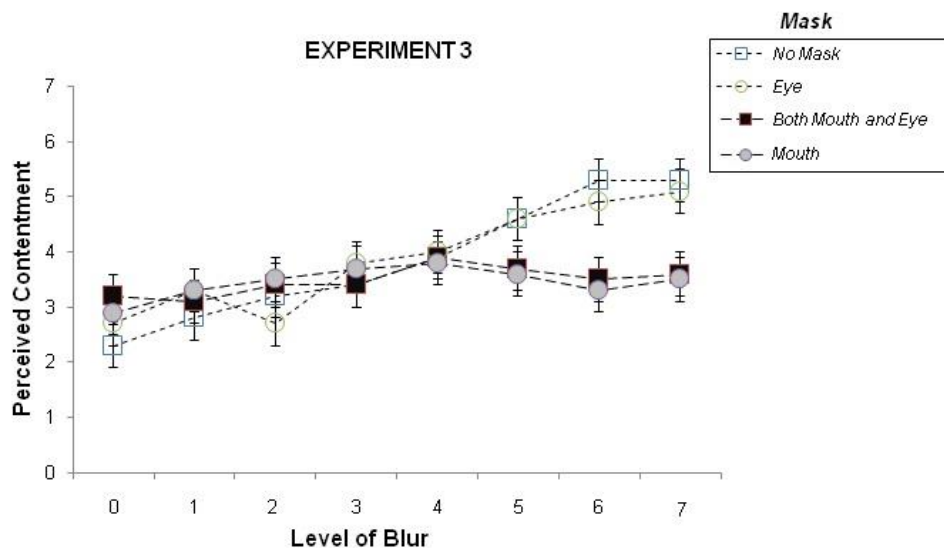

Figure 8: Results of experiment 3. The figure shows a linear trend between Level of Blur and Perceived Contentment in the No Mask and in the Eye Mask conditions. There was no such trend for the Perceived

Contentment in the Mouth only and the Mouth and Eye conditions. Dotted lines favour the view of the trend. Bars indicate standard errors.

As can be seen from Figure 8, the results of experiment 3 support Hypothesis 3 that the uncatchable smile illusion would be mainly attributable to the mouth area of La Bella Principessa. In particular, results show a positive linear trend between Level of Blur and Perceived Contentment in the No Mask and in the Eye mask conditions, whilst there was no such trend in the two conditions in which the mouth was masked.

6. Experiment 4: Distance on perceived mouth slant

The fourth experiment tested Hypothesis 4 that the perceived slant of La Bella Principessa's mouth changes when the distance is manipulated. Specifically, it was hypothesised that the corner of the mouth will appear to take an upward turn when distance is increased.

In this experiment, a digital version of the portrait was projected onto a screen and software was created to facilitate measurement of mouth slant. A between observers experiment was conducted with Viewing Distance as the independent variable with 2 levels: Close vs. Far. The dependent variable was the Perceived slant of the mouth.

6.1. Methods

6.1.1. Observers

20 observers participated in experiment 4 (10 in the Close condition and 10 in the Far condition). All had normal or corrected-to-normal acuity and were naïve with regard to the experimental design. None of them had participated in the previous experiments and they were not familiar with La Bella Principessa' s portrait.

6.1.2. Apparatus and stimuli

An exact sized (33.2 cm in height x 23.8 cm in width) digital version of La Bella Principessa was projected, using a Panasonic PTRW 330 projector onto a screen

connected to an HP Pro-desk computer at 1.80 meters from the floor. The experiment took place in a large room in diffused lighting conditions such that the picture could be seen unimpeded.

A wireless keyboard was placed on top of the desk that, according to the Viewing Distance condition, was placed in order for the observers to be at either 0.5 meters (Close condition) or 8 metres (Far condition) from the screen. The sizes of the retinal images of the portrait in degrees of visual angle were the same as those in experiment 1 (36.8 x 26.8 deg. for the Close condition and 2.4 x 1.74 deg. for the Far condition).

Software was created to measure the mouth slant angle. Using the wireless keyboard, observers could adjust a measurement hairline 0.9 cm long (i.e. the same length of her mouth), placed at the same height and 4 cm to the left of the Principessa's mouth to match its perceived slant. This was then recorded electronically. The interactive measuring tool can be seen in Figure 9.
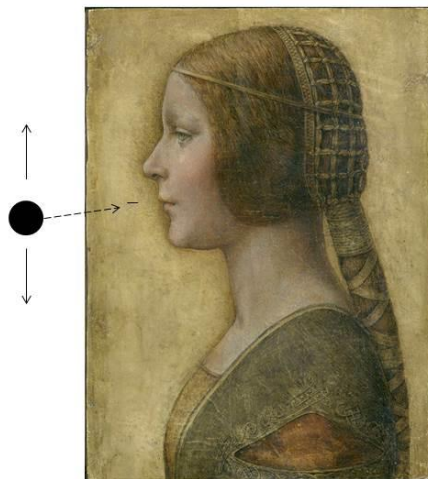

Figure 9: The measurement tool handle used for experiment 4 and 5. The angle measurement line was manipulated by observers to line up with the apparent mouth slant by 'dragging' the 'handle' up or down.

6.1.3. Procedure

Observers viewed La Bella Principessa's portrait projected on the screen. According to the Viewing Distance variable, they were randomly placed at a distance of 0.5 or 8 metres from the screen (i.e. the same distances used in experiment 1).

Observers were equipped with a wireless keyboard and mouse and were instructed to measure the perceived slant of the mouth by dragging the measurement tool handle using the mouse. They were asked to manipulate the line slant, one pixel at a time, the thick line until it was in alignment with the mouth slant (defined by the line of the inner lips). By pressing the spacebar, the perceived mouth slant angle was recorded.

The image was shown after the observers were allocated to their viewing distance condition, so they could see La Bella Principessa from the assigned location only and did not experience any change in the viewing distance.

The image remained on the screen as long the observer desired and the whole session lasted approximately 1 minute.

6.2. Results

An independent-samples t-test revealed a significant effect of the Viewing Distance variable [$t_{(18)} = 18.06$; $p. < 0.01$]; showing a very large effect size (Cohen's d = 7.24).
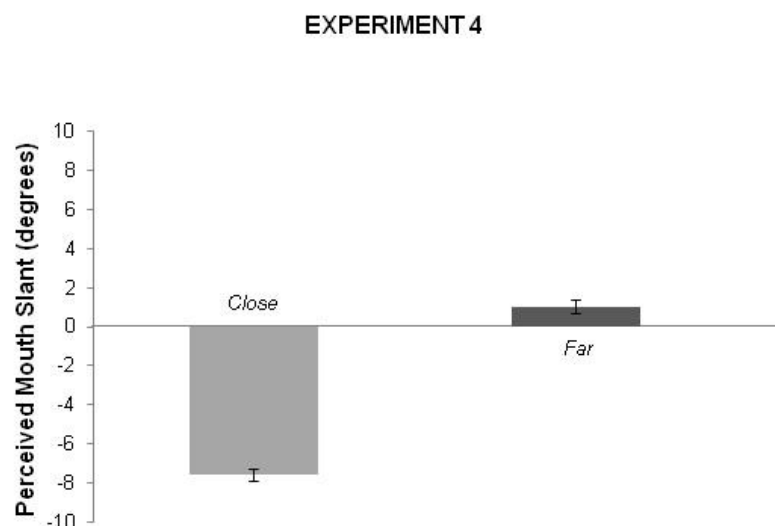
EXPERIMENT 4

Figure 10. Results of experiment 4. The graph shows that the Perceived mouth slant of La Bella Principessa is different when she observed from close-up rather than from distance. Standard errors are indicated by the lines on top of the bars.

As can be seen from Figure 10, the results of experiment 4 support Hypothesis 4 that the perceived slant of La Bella Principessa's mouth changes with the viewing distance. In particular, when the portrait is observed from close-up La Bella Principessa's mouth is perceived to take a downward direction, whereas it is perceived to take an upward slant when she is viewed from a distance.

7. Experiment 5: Blur on perceived mouth slant

The fifth experiment tested Hypothesis 5 that the perceived slant of La Bella Principessa's mouth would change when a digital version of the portrait was presented with different levels of blur. Specifically, it was hypothesised that the corner of the mouth would appear to take an upward turn when blur is increased. For this experiment digital versions of the portrait with progressively increasing levels of blur were used and software was created to facilitate the measurement of mouth slant. A repeated-measures experiment was conducted with Blur as the independent variable with 8 levels of increasing blur. The dependent variable was the Perceived slant of the mouth.

7.1. Methods

7.1.1 Observers

10 observers participated in experiment 5. All had normal or corrected-to-normal acuity and were naïve with regard to the experimental design. None of them had participated in the previous experiments and they were not familiar with La Bella Principessa's portrait.

7.1.2. Apparatus and stimuli

The apparatus were the same as those used in experiment 2 and the same on-screen facility created for experiment 4 was used to measure the mouth slant angle. The same eight versions of La Bella Principessa with different levels of blur previously created for experiment 2 were also used. For each image presentation, observers could adjust a measurement hairline to align it with their perception of the mouth slant angle and record this (see Figure 9).

7.1.3. Procedure

The presentation of images was the same as that used in experiment 2 where observers were shown these in random order on the screen. Observers viewed the stimuli in a well illuminated room at a distance of 50 cm from the monitor. As with experiment 4, observers were instructed to measure the perceived slant of the mouth by dragging the measurement tool handle. By pressing the spacebar, the perceived mouth slant angle was recorded. Following this, as in experiment 2 and 3, a random noise mask was presented on the screen for 1 second prior to the next image being presented. Each image remained on the screen as long as the observer desired and the entire session lasted approximately 10 minutes.

7.2. Results

A Kolmogorov-Smirnov test for the normality of the raw data showed no significant deviation from normality. A one-way repeated measures ANOVA revealed a significant effect for the Level of Blur variable [$F_{(7,63)}$ = 25.42; $p < 0.01$; $\eta p^2 = 0.74$]. The mean angle varied from -10 to +3, according to the level of blur with a standard error of the mean of about 0.5 deg.

Follow-up polynomial contrasts indicated a significant linear effect with the Perceived slant of the mouth increasing with the Level of Blur [$F_{(1,9)}$ = 101.88; *p.* < 0.01; $\eta p^2 = 0.92$].
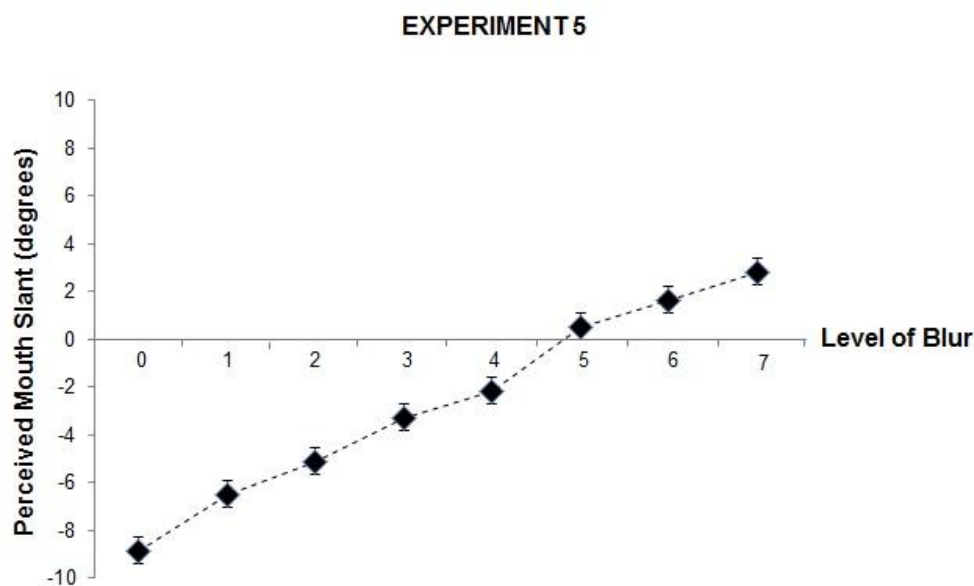

Figure 11:
Results of experiment 5. The graph shows the relationship between the Blur Level and the Perceived

mouth slant in La Bella Principessa's portrait. Dotted lines favour the view of the trend. Bars indicate standard errors.

As can be seen from Figure 11, the results of experiment 5 support Hypothesis 5 that the perceived slant of La Bella Principessa's mouth changes with level of blur. In particular, results show that an increase in the level of blur markedly alters the perception of the mouth slant so that it appears to take an increasingly upward direction.

8. Discussion

The aim of this study was to investigate what we have termed the "uncatchable smile" in Leonardo da Vinci's La Bella Principessa portrait. An exploratory qualitative investigation was first conducted to identify the emotional dimension which is perceived as changing in the portrait. Asking participants to identify this dimension themselves, rather than relying upon a dimension predetermined by the researchers can be considered a form of Grounded Theory approach (Glaser, 1992; Glaser & Strauss, 1967; Strauss & Corbin, 1990; 1997), in which the research investigation starts without prior beliefs, and which allows the research process to shape itself, cutting down on potential researcher bias. In this preliminary qualitative investigation participants were requested to describe La Bella Principessa's facial expression from different distances. A Grounded Theory analysis of the descriptions was then performed and it was found that observers tended to describe her change of expression in terms of contentment. Therefore, the term "contentment" was adopted as the dependent variable for the subsequent experiments. Furthermore, to maximize the power of the statistical tests and, at the same time, to avoid the effect of previous stimuli presentations on subsequent ones, the experiments on Blur were conducted using a repeated measures design, and to eliminate the influence of the previous image a random noise mask was presented after each image presentation. Experiments on Distance were instead conducted using a between-subjects design.

These findings support the hypothesis that there is an "uncatchable smile" illusion in Leonardo da Vinci's portrait of La Bella Principessa, similar to that observed in the Mona Lisa. Specifically, when viewed from close-up and the image is not blurred, the mouth is perceived as slanting downwards but as the observer moves further away or the image is blurred it appears to take an upward turn, and

this perceived change in mouth slant influences the perceived expression of contentment. The results are consistent with those reported by Bohrn et al (2010), for the Mona Lisa, who found that "The elusive smiles in the Mona Lisa condition, which vanished when looked at directly, did affect the appreciation of the face" (p. 380). Moreover, these results are in line with Kontsevich and Tyler's (2004) conclusions on their investigation of the Mona Lisa which showed that the local features of the mouth influence her overall perceived emotional expression.

The story behind La Bella Principessa's portrait is a fascinating one in its own right, both in terms of the academic research undertaken to establish attribution to Leonardo da Vinci and in terms of its poignant human story relating to a young Princess in the court of Milan on the cusp of womanhood, marriage and courtly duties. In considering the princess's situation, it is reasonable to believe that da Vinci wanted to reproduce her inner turmoil in addition to her external features.

Da Vinci is acknowledged as a foremost practitioner in the technique of sfumato whereby contours and edges are eliminated using a subtle graduation of tone that makes objects blend with each other (Hall, 1994). Nagel (1993) describes "sfumato" as meaning not just the appearance of smoke but its disappearance and imperceptible diffusion into the atmosphere. Its use is recognised as a hallmark of da Vinci's technique exemplified in the Mona Lisa and is identified as a contributing factor in her enigmatic smile (Hesslinger et al, 2012). This was confirmed by an X-ray fluorescence spectroscopy study of the Mona Lisa conducted by Philippe Walter and his colleagues at the Centre for Research and Restoration of French Museums (Ball, 2010). This study reveals da Vinci's remarkable control of glaze thickness in the Mona Lisa portrait: the minute shadow effects in her cheek were created by grading chemicals (such as iron-oxide earth pigment and manganese oxide) with extreme precision. It has also been reported by the researchers working for the Laboratoire du Centre de Recherche et de Restauration des Musées de France in collaboration with the European Synchrotron Radiation Facility that da Vinci used up to 30 layers of varnish to achieve the subtle grading, each roughly half the thickness of a human hair (Sharpe, 2010). Given da Vinci's mastery of the technique, and its subsequent use in the Mona Lisa, it is quite conceivable that the ambiguity of the effect was intentional, based on explicit artistic skill and used in line with da Vinci's instruction that "The attitudes also, and all the members, ought to correspond with

the sentiment expressed in the faces" outlined in his *A Treatise on Painting* (da Vinci, 1835, p. 91).

In contrast to Pollaiuolo's Portrait of a Girl that was used as a control in this study, and which does not employ the sfumato technique, the outline of the mouth in La Bella Principessa and the Mona Lisa's portraits is softened with no distinct interface between the outer lips and adjoining facial areas. In addition, there is a well-defined background shadow behind the mouth that blends with the forward facing lips. The use of sfumato together with the shadowy areas around the mouth facilitate blending such that when viewed in coarse resolution, the mouth seemingly changes shape and takes an upward orientation. It is possible that this can convey different information when viewed under different levels of distance or blur (i.e. different spatial resolutions) and that its use in portrait art to enhance ambience may be more widespread than previously believed. From a scientific perspective this study provides another example of da Vinci's ability to influence the viewer's perception of facial expression based on the way different spatial resolutions convey different emotional expressions (Schyns & Oliva, 1997; Vuilleumier et al. 2003), raising questions about the perceptual and cognitive processes involved.

The attribution of La Bella Principessa to da Vinci beyond any reasonable doubt (see Introduction), forges the connection to the Mona Lisa and its enigmatic smile. Now that this connection has been established the existence of an illusion painted prior to that which is well known in the Mona Lisa makes this more recently discovered portrait much more interesting. For example, it is possible that the Mona Lisa may have been developed from techniques which da Vinci experimented with when painting La Bella Principessa. Specifically, the technique that he used to generate the elusive and enigmatic smile in the front-facing portrait of the Mona Lisa may have developed from a technique that he developed in earlier works such as in the profile portrait of La Bella Principessa.

8. Conclusion

This research shows a smile-related illusion in a less well known Leonardo da Vinci portrait which is similar to that identified in the Mona Lisa; La Bella Principessa's mouth appears to change slant depending on the viewing distance and level of blur. Whilst the illusion in La Bella Principessa may well have been

deliberately executed by da Vinci, this cannot be certain. Its inclusion may have involved tacit knowledge – a painter's way of achieving a desired effect unconsciously as described in Gombrich's (1982) *Image and the Eye.* On the scientific front, we envisage further research into the types of responses generated by this kind of illusion such as the thresholds required to trigger the response, and the commonality or otherwise of its use in other Leonardo da Vinci portraits and those painted by other artists.

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