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Material Properties and Image Cues for Convincing Grapes: The Know-how of the 17th Century Pictorial Recipe by Willem Beurs

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Abstract

Painters mastered replicating the regularities of the visual patterns that we use to infer different materials and their properties, via meticulous observation of the way light reveals the world's textures. The convincing depiction of bunches of grapes is particularly interesting. A convincing portrayal of grapes requires a balanced combination of different material properties, such as glossiness, translucency and bloom, as we learn from the 17th century pictorial recipe by Willem Beurs. These material properties, together with three-dimensionality and convincingness were rated in experiment 1 on 17th century paintings, and in experiment 2 on optical mixtures of layers derived from a reconstruction of one of the 17th century paintings, made following Beurs' recipe. In experiment 3 only convincingness was rated, using again the 17th century paintings. With a multiple linear regression, we found glossiness, translucency and bloom not to be good predictors of convincingness of the 17th century paintings, but they were for the reconstruction. Overall, convincingness was judged consistently, showing that people agreed on its meaning. However, the agreement was higher when the material properties indicated by Beurs were also rated (experiment 1) than if not (experiment 3), suggesting that these properties are associated with what makes grapes look convincing. The 17th century workshop practices showed more variability than standardization of grapes, as different combinations of the material properties could lead to a highly convincing representation. Beurs's recipe provides a list of all the possible optical interactions of grapes, and the economic yet effective image cues to render them.

Keywords: Convincingness perception, material perception, material rendering, pictorial cues, Willem Beurs, 17th century paintings, grapes

1. Introduction

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What does it take to paint convincing grapes? According to Willem Beurs (1692; Lehmann and Stumpel, in press), a 17th century Dutch painter, convincingly painted grapes look three-dimensional, glossy, translucent and partly covered with bloom (a waxy coating that naturally occurs on grapes, resulting in a whitish, matte appearance). Here we studied whether these material properties explain the perceived convincingness of grapes depicted in 17th century paintings, and how the pictorial cues that Beurs (1692; Lehmann and Stumpel, in press) prescribed to trigger their perception relate to the perceived material properties.

With the advent of the 'psychology of art' (Arnheim, 1954; Gombrich, 1960), art became an object of scientific interest, worth investigating to disclose new perspectives on our understanding of the human visual system (Cavanagh, 2005; Pinna, 2007; Conway & Livingstone, 2007; Huang, 2009). However, collaborations between artists and scientists are developing at a slow pace due to differences in methods and languages (Spillmann, 2007).

Perception studies referring to the knowledge of painters have mostly focused on depth perception of 3D space and objects in 2D representations (Koenderink *et al.*, 1994; Zimmerman *et al.*, 1995; Koenderink *et al.*, 2011; Wijntjes, 2013; Pepperell & Ruschkowski, 2013; Wijntjes *et al*., 2016). Little attention has been paid to what artists have already discovered about material perception, a recent core topic in vision science (Adelson, 2001; Fleming *et al.*, 2015). Material perception investigates the relationships between optical properties, image cues, and perception of materials from their appearance (see Fleming, 2017) for a comprehensive review). Sayim and Cavanagh (2011) studied the cues used by artists throughout the centuries to depict transparency. Di Cicco *et al.* (2019) found that some of the image features diagnostic for gloss perception, proposed by Marlow and Anderson (2013), were already part of the 17th century pictorial conventions for depicting grapes, namely highlights' contrast and blurriness.

The exceptional realism of Dutch 17th century paintings is widely acknowledged by scholars in art history (Slive, 1962, 1998; Westermann, 2005; Lehmann, 2007; Pincus, 2011; Bol & Lehmann, 2012). While seeking the most life-like representation of reality, Dutch painters became masters in the *stofuitdrukking*, a Dutch term that can be translated as 'rendering of texture[2]' or 'expression of stuff'. According to De Vries (1991), the *stofuitdrukking* is distinctive of Dutch Golden Age paintings, given that "nowhere else was so much effort expended on attaining the greatest possible likeness between a real object and its depiction with regard to surface structure, color, and the play of light".

[2] The term 'texture' is often used by art historians to indicate all material properties, not limited to the more formal statistical meaning often used in vision science.

Painters understood long before the advent of vision science that the human visual system seizes key information from the surroundings, overlooking unnecessary details and physical inaccuracies (Bertamini *et al.*, 2003; Mamassian, 2004; Ostrovsky *et al.*, 2005). They have exploited the capability of the visual system of disregarding impossible and simplified physical phenomena, to abbreviate the rendering of materials with perception triggering pictorial shortcuts (Cavanagh, 2005). Such perception-driven approach has been also used for photo-editing applications by Khan *et al.* (2006). Schmidt *et al.* (2016) reviewed art-based material editing methods that discount the laws of physics when necessary to achieve the desired appearance. This is the case for, for instance, the artist-friendly hair rendering system developed by Sadeghi *et al.* (2010). They proposed an intuitive hair shader method based on visual cues whose color, shape or position can be manipulated separately, rather than relying on intrinsic physical parameters, like the refractive index, that affect the whole final appearance in unpredictable ways. Bousseau (2015) reported that artistic principles and image shortcuts can vividly represent the appearance of materials in computer graphics, optimizing the time-consuming task of rendering algorithms. Convincing (but not necessarily physically realistic) rendering of fruits and vegetables finds a wide range of applications, from movies and animations (Cho *et al.*, 2007), to virtual reality experiments for food loss reduction (Verhulst *et al.*, 2017).

1.1. The Pictorial Recipe for Grapes in "The Big World Painted Small"

While the number of perceptual experiments using paintings as stimuli is limited, the use of art historical writings in material perception science is virtually nonexistent. Lehmann *et al.* (2005) investigated the texture of trees and found that the attributes that best describe the appearance of foliage were already noted by Leonardo da Vinci in his *Trattato della pittura*. Written sources are used in technical art history to shed light on the painters' practices (Lehmann, 2007; Smith & Beentjes, 2010), and to analyze and reconstruct the artworks (Dietemann *et al.*, 2014; Stols-Witlox, 2017). As such, they can serve as complementary information to disclose the perceptual knowledge inherent of paintings. In contradistinction, understanding the mechanisms behind our perception of paintings can help to systematically describe paintings.

The depiction of surfaces and materials during the 17th century was determined by workshop traditions and by the standardization of recipes (Wiersma, 2019). For example, the method for painting grapes deployed by Jan Davidsz. de Heem is similar to the recipe given by Beurs in the art treatise *The big world painted small* from 1692 (Wallert, 1999, 2012; De Keyser *et al.*, 2017). This treatise is a compilation of color recipes for oil painting, a recapitulation of 17th

century practice. It describes the best choice of color (pigment) combinations for the defining visible properties of several phenomena, objects and beings.

Recipes for objects and edibles that occur in still-life paintings received most attention in the treatise. The recipe for grapes is one of the most extensive in the book; it requires nine to ten steps, depending on the color of the bunch. When describing plums, berries and even lemons, Beurs (indirectly) refers to how the translucent pulp of the grape is depicted, treating this fruit recipe as the basis for many others. Given the number of surface effects and material properties grapes display, this makes sense. Grapes have a multilayered structure (Fig. 1), so the relationship between the optical properties of glossiness, translucency and bloom can be complex and not easily predictable. The skin covers the pulp, which is made of cells containing the juice, and comprehends a vascular system for transportation of water and nutrients, and the seeds. The skin is naturally covered with bloom, that (partly) diffusely reflects light hindering the process of subsurface scattering and the specular reflections. However, the influence of bloom on translucency and glossiness is not straightforward, since the bloom can be unevenly spread over the surface and it can have varying thickness. The process of subsurface scattering is further complicated by the heterogeneous internal structure of the grapes, adding to the complexity of the grapes' appearance.

Figure 1. Schematic representation of the multilayered structure of a grape (adapted from an illustration by Mariana Ruiz Villarreal, released to the public domain).

The recipe for white grapes is as follows: (Lehmann and Stumpel, in press; Beurs, book 5, chapter 1):

> "White grapes are laid in with English ash [a greyish blue], yellow lake [a translucent bright yellow paint], and white for the lit side. But for the shadows, ash, yellow lake, and black have to do the work. The reflections however, require only a little ash but somewhat more yellow lake**.**

> After white grapes have been painted in this way the bloom can be created with ultramarine and white, or with a little lake mixed into a white oil, which is scumbled over the grapes. But to render the bloom in shadows, black, lake, and white are needed. Once all this has been done, the grapes have to be given a sheen on the lit side (where there is no bloom) with white that is gently blended in, and the reflections glazed with only yellow lake, as the occasion demands.
>
> But the seeds in the grapes, which shine through in the ripe ones as they are usually painted, must not be forgotten. These are made visible by mixing light ochre with a little ash and white into the yellow lake, and for the shadows, black."

The recipe (Beurs, 1692; Lehmann and Stumpel, in press) starts with instructions to paint the lit and shaded side of the grapes, providing the first impression of their three-dimensional shape (Metzger, 1936). The following step is to render the internal reflections along the edges of the grapes, a cue of the permeability to light which provides the translucent look. When the paint is dry, the bloom layer is scumbled on top, not too opaque, following a seemingly random design per grape to keep the translucent peel visible here and there and apt for highlights - the next step. Highlights are the basic visual cues for glossiness (Beck & Prazdny, 1981; Berzhanskaya *et al*., 2005). A glaze deepens and saturates the pulp's shadow color where the edge reflections are visible. The glaze is made using a translucent pigment and a fairly large amount of binding medium (Bol, 2012). Last in the recipe, the impression of a seed within the pulp is given by defining part of its shape. A visible seed is a further indication of the translucent property of the grapes.

In this discussion it is important to distinguish between the physical properties of materials, lighting and shape, their depiction, and their perceptions. These three domains must be systematically related, but their mutual relationships do not have to be dictated by physics in the sense that perceived physical realism can only be attained by physically realistic rendering. Perceived physical realism is a perceptual entity and therefore determined by perception or intelligent interpretations. Therefore, 'physical realism' is replaced by 'convincingness' in this paper, to clearly distinguish it as a perceptual attribute. In painting, it needs understanding of which key image features trigger certain perceptions. The aim of this paper is to understand which features those are for grapes, and how those are related to the perceived material attributes prescribed by Beurs to paint a convincing bunch of grapes (1692; Lehmann and Stumpel, in press).

2. Methods

We investigated whether Beurs' material attributes explain convincingness of grapes via three rating experiments. We tested the perception of convincingness, three-dimensionality, glossiness, translucency, and bloom for images of 17^{th} century paintings in experiment 1, and for optical mixtures of layers obtained reproducing one of the 17^{th} century paintings in experiment 2. In (control) experiment 3, only the convincingness of the 17^{th} century paintings was rated. These data were correlated to the convincingness ratings of experiment 1 to test if raters, provided and not provided with the material attributes that should explain convincingness, agreed on how convincing the painted grapes looked.

2.1. Participants

Different groups of observers took part in each experiment. Two groups of nine, and a group of ten naïve observers, with normal or corrected vision, participated in experiments 1, 2 and 3 respectively. They provided written consent prior to the experiment and received a financial compensation. The experiments were conducted in agreement with the Declaration of Helsinki and approved by the Human Research Ethics Committee of the Delft University of Technology.

2.2. Stimuli

2.2.1. Experiments 1 and 3

In experiments 1 and 3, we used 78 high-resolution digital images of 17^{th} century paintings, downloaded from the online repositories of several museums[3]. The stimuli were presented as squared cut-outs containing the target bunch of grapes (Fig. 2).

[3] A numbered list of all the squared cut-outs used in the rating experiments can be found in the supplementary material. Each image in the list has an embedded link to the relative museum repository website, where the original images can be found.

Figure 2. Example of a stimulus presentation, as squared cut-out around the target bunch of grapes. *Still Life with Fruit, Fish and a Nest*, Abraham Mignon (1675), oil on canvas. Downloaded from the online repository of the National Gallery of Art, Washington, DC, USA.

2.2.2. Experiment 2

A bunch of grapes painted by Jan de Heem (Fig. 3), judged among the most convincing in experiment 1 and 3, was reconstructed according to Beurs' recipe, to make the stimuli for experiment 2. The pictorial procedure of De Heem, especially for grapes, was shown to match rather well the recipe of Beurs via scientific analysis of his paintings (Wallert, 1999, 2012; De Keyser *et al*., 2017). Hence, the second author, who is also an experienced painter, implemented Beurs' procedure in a reconstruction. The bunch was painted on fine linen, prepared with a colored ground following Beurs': a mixture of umber and white was applied by hand in several layers. This is not how De Heem prepared his canvas: there, a grey or grey-brown was applied on top of a red ochre. Since the laboratory where the painting was made was not equipped with a fume hood, no historical pigments were used, but modern tube paints. For the yellow glaze, boiled linseed oil was added to a bit of bright yellow tube paint. The colors were selected to match the paints mentioned in Beurs' text visually.

We digitized the reconstruction process to access images of the painting layers, corresponding to the pictorial cues given in the recipe.

Figure 3. Bunch of grapes representing Beurs' recipe, which formed the example for the reconstruction and stimuli of experiment 2. *Garland of Fruits and Flowers*, Jan Davidsz. de Heem (probably 1650-1660), oil on canvas. Downloaded from the online repository of the Mauritshuis, The Hague, The Netherlands.

The painting reconstruction and its digitization were carried out in a darkened room with no windows to ensure a constant lighting. The only light source present in the room was a professional studio LED lamp, a Rotolight ANOVA HD eco flood (color temperature=5000 K). All the photos, for a total of 1124, were taken with a camera Canon 5D Mark II (shutter speed=1/80, aperture=f/8.0, ISO=500). High resolution images were acquired automatically every 10 seconds, using the program Canon EOS Utility 3 (Canon Inc., USA).

Figure 4 (top) shows the six stages of the reconstruction corresponding to each step given by Beurs (1692; Lehmann and Stumpel, in press). To generate the stimuli for the experiment we used the optical mixing procedure (Griffin, 1999; Pont *et al*., 2012), an image combination technique that resembles the systematic layering approach of painters (Zhang *et al*., 2016). The layers recombined via optical mixing, were obtained by subtracting the first image in Fig. 4 (top) from the second, the second from the third, etc. The resulting layers, carrying the individual cues, are shown in Fig. 4 (bottom).

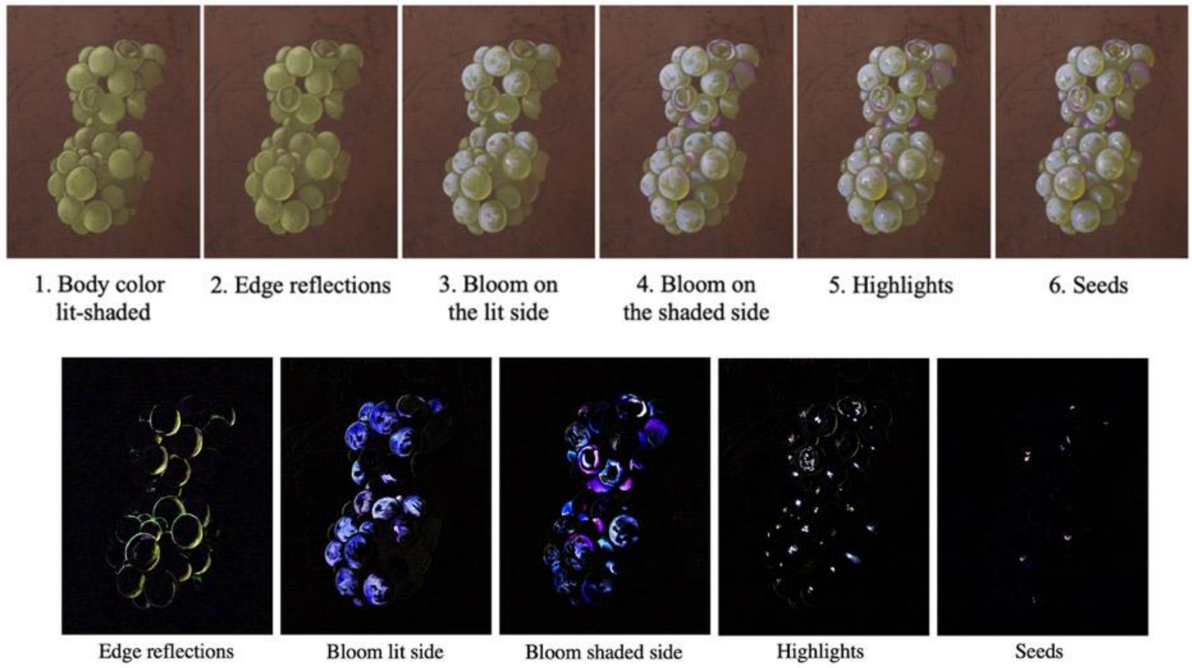

Figure 4. Top) sequence of reconstruction steps of the bunch of grapes in *Garland of Fruits and Flowers* according to Beurs' recipe, made by Lisa Wiersma. Each image corresponds to a step in the recipe. Bottom) layers representing pictorial material cues for edge reflections, bloom, specular highlights and seeds, obtained from subtraction of the steps in the reconstruction process.

Using the optical mixing interface, we made 162 stimuli[4]. We used the interface to control and manipulate the weights of each layer, which could be placed anywhere between 0 and 100%. The stimuli were made via the following combinations of the layers' weights: the first layer,

[4] The images of the 162 combinations and their corresponding layers' weights are available in the supplementary material.

corresponding to the body color, was kept constant at 100%; the layers 2 to 5 (edge reflections, bloom on the lit and on the shaded side, and highlights) were taken with weights of 0, 50 or 100%; the layer of the seeds was either 0 or 100%. Some examples of the stimuli and their change in appearance according to the weights of the layers are shown in Fig. 5.

Figure 5. Examples of the stimuli obtained with the optical mixing interface by combining different weights of the layers. From left to right the weights of the layers edge reflections, bloom on the lit side, bloom on the shaded side, specular highlights and seeds, are: 1) 50%, 0, 50%, 100%, 100%; 2) 50%, 0, 0, 0, 0; 3) 100%, 100%, 100%, 100%, 100%; 4) 100%, 0, 0, 100%, 100%; 5) 0, 100%, 100%, 0, 100%.

2.3. Procedure

The procedure was the same for experiments 1 and 2, with the only difference of the stimuli presented. Participants were asked to rate on a continuous 7-point scale the five attributes derived from Beurs: three-dimensionality, translucency, glossiness, bloom and convincingness. A written definition of each attribute and an explanation of the polarity of the scale, were provided before starting the experiment. The attributes were defined as follows:

- Translucency: how translucent do the grapes appear to you? Low values indicate that no light passes through the grapes and the appearance is opaque; high values indicate that some light passes through the grapes.
- Glossiness: how glossy do the grapes appear to you? Low values indicate a matte appearance; high values indicate a shiny appearance.
- Bloom: it is the whitish layer covering the surface of the grapes. How much bloom appears to be on the grapes? Low values mean that there is no bloom at all; high values indicate that the grapes are completely covered with bloom.
- Three-dimensionality: how three-dimensional do the grapes look? Low values indicate a flat appearance; high values indicate that the grapes look three-dimensional.

- Convincingness: how convincing is the representation of the grapes' appearance? To what extent do you recognize the features that you would expect to see in a real bunch of grapes? Low values mean that the representation is not convincing at all; high values indicate that all the expected features necessary to recognize a real bunch of grapes are present.

The understanding of the meaning of translucency, glossiness and bloom was verified with a two-alternative choice test. A pair of photographs of real grapes was shown to the participants to test the three attributes, with one photo having the attribute and one not. Observers were asked to choose which one was more translucent, bloomy or glossier. They were given feedback on the answer, and if they were able to choose the right options they could start the experiment. The question presented on the screen was "How [attribute] is this bunch of grapes on average?". The attributes were rated separately in five blocks, in a random order (between and within each block), resulting in 390 trials per observer for the 78 stimuli of experiment 1, and 810 trials for the 162 stimuli of experiment 2.

In experiment 3, participants rated convincingness only, for the same stimuli as in experiment 1, on a continuous 7-point scale. The 78 stimuli were rated three times in random order in one block, for a total of 234 trials per observer.

The experiments were conducted in a darkened room. The stimuli were presented against a black background, on an EIZO LCD monitor (CG277). Color consistency was ensured by calibrating the monitor before each session, with the software "Color Navigator 6" (EIZO, Japan; version 6.4.18.4; brightness=100 cd/m^2, color temperature=5500 K). The interfaces of the experiments were programmed in MATLAB R2016b (MathWorks, Natick, MA, USA), using the Psychtoolbox Version 3.0.14 (Brainard, 1997; Pelli, 1997; Kleiner *et al*., 2007).

Prior to the experiments, participants had the possibility to go through all the stimuli in order to get an overview of the stimulus range. No time limit was given to complete the tasks.

3. Results

3.1. Consistency between subjects

We checked for the consistency between raters of each experiment. To minimize possible effects of unequal interval judgements, the data of all observers were normalized before averaging. To measure the agreement between observers, the ratings of each participant were correlated with the mean ratings of the other participants.

For experiment 1, all correlations were positive and significant ($p<0.001$), ranging from 0.81 to 0.52 for glossiness, 0.72 to 0.39 for translucency, 0.63 to 0.37 for bloom, 0.77 to 0.41 for three-dimensionality and 0.71 to 0.48 for convincingness. In Fig. 6 we plotted the mean correlations of the ratings to visualize the dependency of the agreement between participants on the attributes. Participants were most consistent when rating glossiness, and next convincingness and three-dimensionality. The least agreement was found for translucency and bloom.

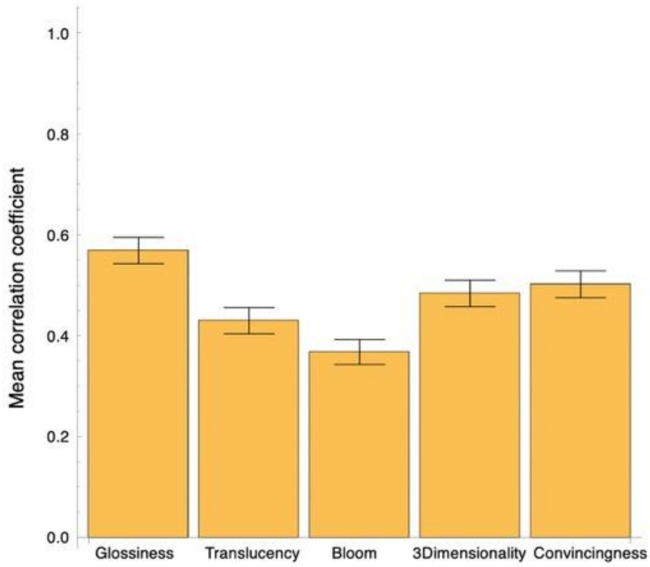

Figure 6. Mean correlations of the attributes rated in experiment 1. The error bars indicate the standard error of the mean.

For experiment 2, the correlations were all positive and significant (p<0.001), ranging from 0.82 to 0.39 for glossiness, 0.72 to 0.30 for translucency, 0.87 to 0.62 for bloom, 0.76 to 0.36 for three-dimensionality and 0.77 to 0.46 for convincingness. In Fig. 7, the mean correlations of the ratings for each attribute are plotted. The inter-rater agreement again depended on the attribute rated. To the contrary of what we found for experiment 1, people agreed most on the rating of bloom. The order of the other mean correlations was the same as in experiment 1, and the attribute translucency was rated again less consistently across participants. Overall the agreement on convincingness was somewhat lower than in experiment 1.

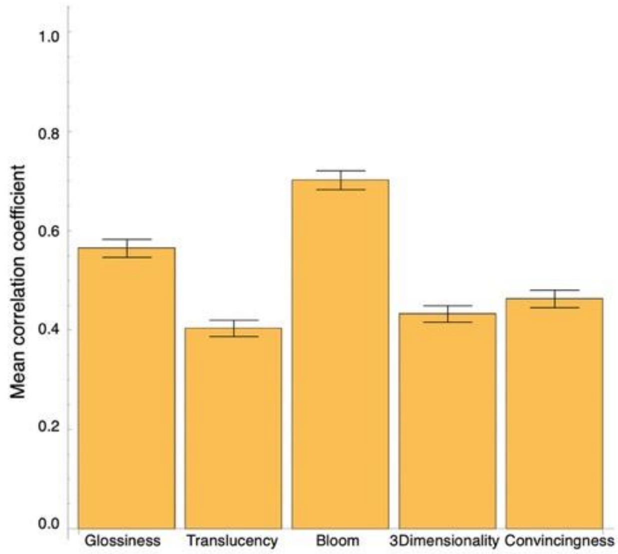

Figure 7. Mean correlations of the attributes rated in experiment 2. The error bars indicate the standard error of the mean.

The inter-rater agreement was calculated also for experiment 3. In this experiment participants were asked to rate convincingness three times per stimulus. We took the median of the three repetitions to account for potential outliers, and then calculated the correlations between observers. All correlations were positive and significant (*p*<0.001) ranging from 0.85 to 0.53. The mean intra-rater correlations ranged between 0.8 and 0.48 (*p*<0.001). The high agreement between and within subjects suggests that convincingness perception was consistent and stable.

3.2. Convincingness Perception Explained by Beurs' Recipe

In experiment 1, convincingness was highly correlated with three-dimensionality, it was moderately but significantly correlated with glossiness and translucency, and it showed no correlation with bloom (Fig. 8).

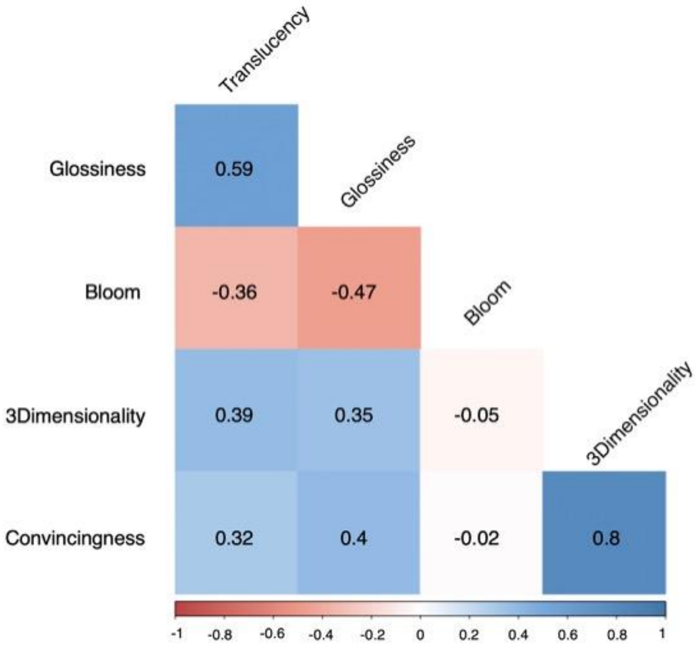

Figure 8. Correlation matrix of the mean ratings of the attributes in experiment 1. Each cell reports the value of the non-partial correlation coefficient.

To predict perceived convincingness from the attributes' ratings, we used multiple linear regression. The best fitting model (equation 1) carries only glossiness and three-dimensionality as significant predictors. This model explains 66% of the variance of perceived convincingness.

$$Convincingness = 0.01 + 0.1\ Glossiness + 0.8\ ThreeD \quad (1)$$

However, the semi-partial correlation between convincingness and glossiness is 0.065, meaning that the term glossiness in the model does not explain any additional variance of convincingness above what is already explained by three-dimensionality. The contribution of glossiness, which appears to be redundant, can be deleted. The best fitting model for convincingness of the 'average' bunch of grapes has only three-dimensionality as significant predictor (equation 2), with an explained variance of 65%.

$$Convincingness = 0.04 + 0.84\ ThreeD \quad (2)$$

In experiment 2, convincingness was highly and positively correlated with glossiness, translucency and three-dimensionality, and negatively with bloom (Fig. 9).

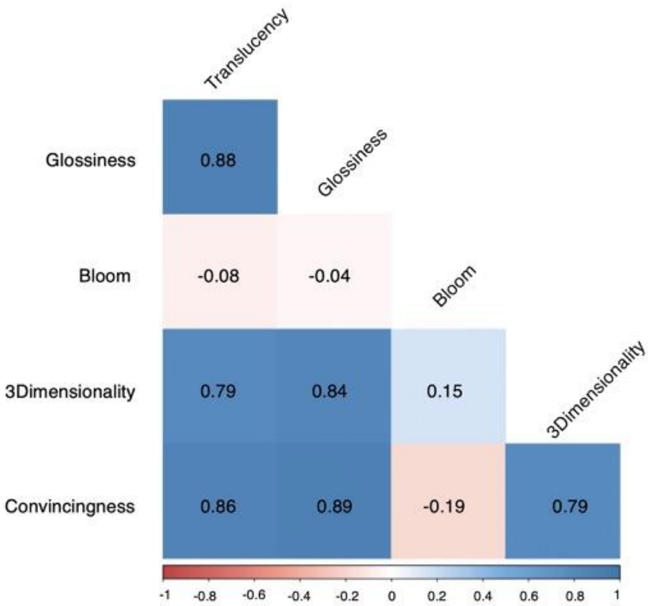

Figure 9. Correlation matrix of the mean ratings of the attributes in experiment 2. Each cell reports the value of the non-partial correlation coefficient.

A multiple linear regression of the rated attributes resulted in the best fitting model carrying all the attributes as significant predictors of perceived convincingness (equation 3). The variance explained by this model is $r^2 = 84$ %.

$$Convincingness = 0.07 + 0.3\,ThreeD - 0.14\,Bloom + 0.24\,Translucency + 0.4\,Gloss \qquad (3)$$

3.3. Pictorial Cues for Convincingness

We found that for the bunch of grapes reproduced in experiment 2, convincingness on average was related to all the attributes. Now we want to know which combinations of pictorial cues produced the most and the least convincing representations of the bunch. By manipulating the weights of the layers we could control for the presence of the cues in the images.

The weights of the layers' (edge reflections, bloom on the lit side, bloom on the shaded side, specular highlights and seeds) combinations for the least and most convincing grapes on average were (50%, 0, 0, 0, 0) and (50%, 0, 50%, 100%, 100%), respectively. The corresponding images are shown in Fig. 5 (the first two images from the left).

The least convincing bunch had (excluding the base) none of the layers and related cues of the material properties given by Beurs (1692; Lehmann and Stumpel, in press). The only exception was the weight of the edge reflections layer, being 50% instead of 0. However, a T-test showed that for the bunch perceived to be least convincing the convincingness rating was not significantly different (p>0.05) from that of the bunch having all layers set to 0. The most convincing bunch instead, presented all the prescribed layers except for the bloom. Following

Beurs, we expected the image with all the layers set to 100% (see Fig. 5, third image) to be the most convincing, but a T-test showed that those two images were significantly different ($p<0.01$) in perceived convincingness.

The weights of the pictorial cues were also correlated to the material properties that they were supposed to trigger. The weights of the layers bloom on the lit side and bloom on the shaded side had respectively $r=0.92$ ($p<0.001$) and $r=0.33$ ($p<0.001$) with perceived bloom. The weights of the highlights' layer correlated highly and significantly both with glossiness ($r=0.94$, $p<0.001$) and translucency perception ($r=0.87$, $p<0.001$). The weights of the edge reflections layer had a moderate but significant positive correlation with translucency ($r=0.19$, $p<0.001$).

3.4. Correlation between Convincingness Ratings in Experiment 1 and 3

To test the assumption that convincingness was judged consistently, regardless the amount of information given or actively directing attention towards certain aspects, we plotted the correlation between the average ratings of experiments 1 and 3, i.e. with and without specifying the material attributes (Fig. 10).

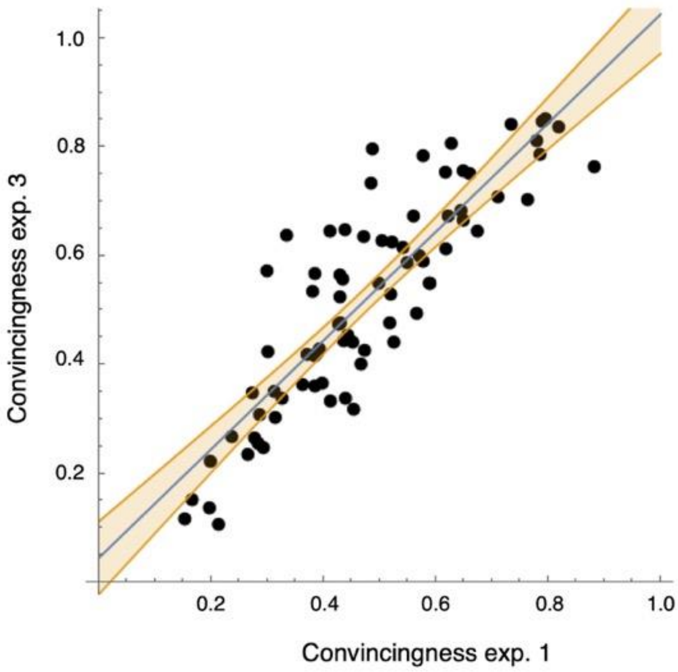

Figure 10. Scatterplot of the correlation between the average convincingness ratings of experiment 1 and of experiment 3. $r=0.87$, $p<0.001$; the area around the fit line represents the 95% confidence interval.

The correlation coefficient between the ratings was high, positive and significant (r=0.87, p<0.001). However, when comparing the Cronbach's alpha values of the two experiments (0.98 for experiment 1 and 0.91 for experiment 3) with a T-test, we found a significant difference between the two values (p<0.05). This suggests that participants in experiment 1 were more consistent with each other when rating convincingness compared to participants of experiment 3.

4. Discussion

The order of the mean correlations of the attributes in experiment 1 and 2 was the same except for bloom. Bloom was perceived least consistently across subjects in experiment 1 (Fig. 6), but it had the most agreement in experiment 2 (Fig. 7). To the contrary of experiment 1, the stimuli of experiment 2 represented variations of the same bunch of grapes, with a clear depiction of the bloom which made it easier to interpret it in a highly consistent way. This was confirmed by the high correlation between bloom perception and the weights of the bloom layer in experiment 2, indicating that the bloom cue was a clear trigger of bloom perception for the reproduced bunch of grapes. However, the bloom cue might have been less obvious in the stimuli of experiment 1, probably due to the different painting techniques and the diverse variety of depicted grapes. This could result in different styles to render the bloom layer, which may have been perceived as a diffuse reflection when applied thinly, rather than something covering the surface, and vice versa. This was maybe the case for the bunch shown in Fig. 11, whose bloom perception caused the most disagreement.

Figure 11. Stimulus whose bloom perception was rated the least consistently in experiment 1. *Fruit Piece*, Jan van Huysum (1722), oil on panel. Downloaded from the online repository of the J. Paul Getty Museum, Los Angeles.

Translucency was perceived the second least consistently in experiment 1 (Fig. 6) and the least in experiment 2 (Fig. 7). The optical phenomenon that elicits translucency is subsurface scattering, i.e. light enters a body, it is partly absorbed and partly scattered within the body, and it reemerges at different locations of the surface. The physics of translucency is well-known, but the visual cues that trigger its perception are less well understood (but see Fleming & Bülthoff, 2005). Koenderink and Van Doorn (2011) investigated the shape from shading theory for translucent objects and concluded that determining general laws to explain the appearance of translucent objects is far from trivial, given that it depends on illumination and viewing directions and on the object's shape. Since the appearance of translucent objects is dependent on so many factors, it varies enormously in ecologically valid conditions, which might explain the relatively low consistency found in our experiments.

On the other hand, the agreement between participants on glossiness was the highest in experiment 1 (Fig. 6) and the second highest in experiment 2 (Fig. 7). In case of experiment 2, the high agreement can be easily explained by the highlight cue, whether it was present or absent from the layers' combinations. In experiment 1, the high agreement shows that participants were relying on a common set of cues to make their judgements. In the stimuli of experiment 1, the way of rendering the highlights on the grapes was dependent on the personal style of the painter. Differences in the application of the brushstrokes, e.g. fine and invisible or rough and discernible, could have affected the perceived magnitude of glossiness, if people were basing their judgements on the realism of the highlights. In another study (Di Cicco, Wijntjes & Pont, 2019), we found the main predictor of glossiness perception to be the contrast of the highlights, followed by their blurriness, despite how realistically the highlights were depicted. An example is shown in Fig. 12. The bunch on the left was perceived to be significantly glossier (p<0.05) than the one on the right, even though its highlights look poorly realistic, and are recognizable as white dubs of paint, but with high contrast and sharp nonetheless.

Figure 12. Two stimuli showing that glossiness perception was dependent mostly on the contrast and sharpness of the highlights rather than on how realistically the highlights were depicted. The bunch on the left was perceived as glossier than the one on the right. Left) *Still Life with Silver-gilt Bekerschroef with Roemer*, Abraham Hendricksz. van Beyeren (1640-1670), oil on panel. Downloaded from the online repository of the Rijksmuseum, Amsterdam. Right) *Garland of Fruits and Flowers*, Jan Davidsz. de Heem (probably 1650-1660), oil on canvas. Downloaded from the online repository of the Mauritshuis, The Hague.

The agreement was medium on the perception of three-dimensionality in experiment 1 (Fig. 6). In this case, it is possible that the realism of the 3D depiction was confounded with the magnitude of the perceived depth. An increase in the magnitude of depth perception is known to be associated with increased perception of realism of three-dimensionality (Ames, 1925; Koenderink, Van Doorn, & Kappers, 1994), but the latter also depends on the precision of depth representation and perception (Hibbard, Haines & Hornsey, 2017), which might cause inconsistencies.

To test whether Beurs' attributes explained convincingness perception of grapes, we performed multiple linear regressions of the ratings, both from experiments 1 and 2. For experiment 1, we found that three-dimensionality was the only significant predictor for perceived convincingness (equation 2). In real life grapes are three-dimensional, providing a straightforward explanation for the fundamental role of three-dimensionality in convincingness perception. However, a further explanation for the high correlation between three-dimensionality and convincingness could be ascribable to a confounding effect of the realism of the 3D depiction being rated instead of its magnitude. The material properties, translucency, bloom and glossiness, could not be encompassed in a single regression model with defined weights that could fit each and every bunch of grapes. Due to the wide variety of grapes, the best material attributes' combination needs to be tailored on the single case. Figure 13 shows three examples extracted from the 15% most convincing grapes of experiment 1. The bar charts of the average ratings, paired with the corresponding stimulus, show very different patterns in the material attributes, all leading to a judged to be convincing appearance. Note that, even though on average we found convincingness to be positively correlated with glossiness and translucency (Fig. 8), this does not imply that these material properties should be increased to their maximum in order to trigger the most convincing appearance. We could not define the appropriate amounts of glossiness, translucency and bloom, we could just recognize, as Beurs also did in his recipe (1692; Lehmann and Stumpel, in press), that grapes can show all these optical interactions, but the weights of their combination for the most convincing result is left to decide to everybody's own "schema" (Gombrich, 1960) of grapes.

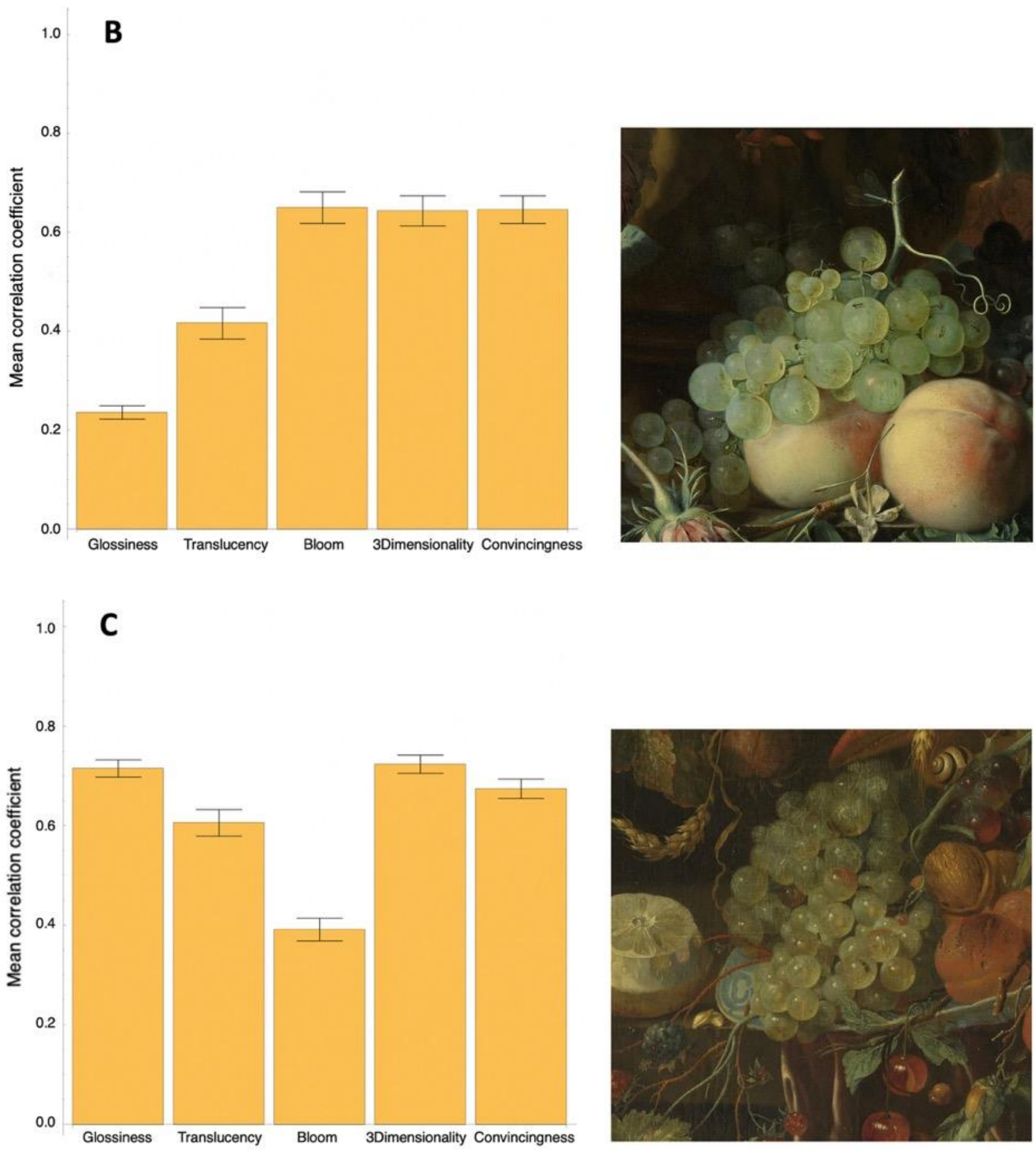

Figure 13. Mean ratings of the attributes rated in experiment 1 for three of the 15% most convincing stimuli. The error bars indicate the standard error of the mean. A) *Marble Bust surrounded by a Festoon of Fruit*, Jan Frans van Son (1680-1718), oil on canvas; B) *Still Life with Flowers and Fruit*, Jan van Huysum (1721), oil on panel; C) *Still Life with Fruit and a Lobster*, Jan Davidsz. de Heem (1640-1700), oil on canvas. Downloaded from the online repository of the Rijksmuseum, Amsterdam.

The convincingness of the bunch of grapes reconstruction tested in experiment 2, was best predicted by all the attributes (equation 3), even though the bloom had a more nuanced contribution compared to Beurs' instructions – the most convincing grapes were found to have no bloom on the lit side and 50% on the shaded side. The bloom layer naturally occurs on grapes, and it is even considered a parameter for postharvest fruit quality measurement (Mukhtar *et al*., 2014). However, the presence of bloom on the surface of the grapes often lead to a negative impression of the naturalness and quality of the fruit (Ma *et al*., 2016). To meet consumers' expectations, grapes are usually sold polished in supermarkets, reducing our interaction and association of bloom with grapes. Participants may have also not associated bloom with convincingness because the bunch in the reconstruction was painted out of context. It was placed isolated against an umber ground, which may have overdone the visual effect of the cues, especially the bloom. In future reconstructions, we intend to include (part of) the background so as to avoid this possibility. Furthermore, it might be possible that the bloom layer was simply painted too thick in the reconstruction.

We further studied the relationship of Beurs' pictorial cues with perception of convincingness and the material attributes, in experiment 2. The layers' combination perceived least convincing implicitly complied with Beurs' prescription given that they were all set to 0, or it was not significantly different from the one with all the layers set to 0. The only slight exception concerned the weight of the edge reflections layer. This might be due to the fact that during the painting of the first step of the recipe, a light part was already laid down along the edge of some of the berries as preparation for the second step, i.e. the application of the edge reflections. The colors prescribed to paint the lit side and the reflections are almost the same. Thus, it could be visually misleading as if also with weight zero of the edge reflections layer, the reflections were already there; and the difference between 0 and 50% is rather subtle (Fig. 14).

Figure 14. The three weights of the edge reflections layer: left 0%, center 50%, right 100%.

The most convincing combination had all the layers except bloom, confirming the result of the predictive model. Its convincingness rating was significantly different from the image with all the layers set to 1, which according to Beurs should result in the most convincing appearance. Beurs' recipe, though, is not a strict set of rules and there is no definition for how the weights of the layers should be distributed to get the optimal result, leaving room to the artist's personal interpretation. Additionally, as discussed above, the effect of the bloom cue may have been exaggerated by the lack of context and background or too thick painting.

We tested the assumption that convincingness was judged consistently despite the amount of information given and attentional focus on specific aspects. In experiment 3, the observers were not explicitly attending our candidate attributes next to convincingness, but we still found high correlation with convincingness ratings of experiment 1 (Fig. 10). Therefore, we assume that their judgements were based on similar features. An interesting exception is the bunch shown in Fig. 11, which was rated moderately convincing in experiment 1 but highly convincing in experiment 3. As already noticed, this bunch caused the most disagreement on the perception of bloom in experiment 1. When the patina on the surface of the grapes was identified as bloom, the perception of convincingness dropped, contributing negatively to the overall mean convincingness which resulted to be moderate. In experiment 3, the same bunch was perceived to be highly convincing probably because participants were not questioning the nature of the haziness of these grapes, since they were not instructed to look for bloom. The Cronbach's alpha values of perceived convincingness in both experiments were above 0.9, demonstrating the high inter-rater agreement, but these values were also significantly different. Participants of experiment 1 were more consistent with each other than participants of experiment 3. Actively looking for the material attributes in experiment 1 may have made it easier for participants to judge convincingness, probably due to a process of perceptual learning and selective attention for the relevant cues (Goldstone, 1998).

5. Conclusions

In the present study we aimed to determine which properties, among the ones prescribed by Beurs in his recipe, are relevant for a convincing depiction of grapes.

The prototype of 'convincing grapes' does not exist. The material properties prescribed by Beurs present a wide range of combinations that can lead to convincing appearances. We have shown that convincingness of grapes painted throughout the 17th century by different artists, was predicted by three-dimensionality only; whereas the influence of glossiness, translucency and bloom was case-dependent. The 17th century workshop traditions and recipes thus show more variability than standardization for grapes. However, when we considered only one bunch of grapes, all the attributes prescribed by Beurs were predictors of convincingness, with bloom being a negative predictor. This was contrary to what we expected, but likely ascribable to a limitation of our stimuli. We showed that people judged convincingness consistently, but they tended to agree more when also the material attributes were provided. This might be due to processes involving more understanding and attention for the pictorial cues with regard to the material. Beurs grasped the basic optical interactions of grapes with light and translated them into those effective pictorial cues. Disclosing and making explicit the pictorial cues and the visual dimensions along which perceptual convincingness was achieved by painters, is an important contribution not only for vision science and art history, but also for the field of computer rendering. We have shown that research on material perception can benefit from the study of art historical writings and from the body of 17th century naturalistic paintings.

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