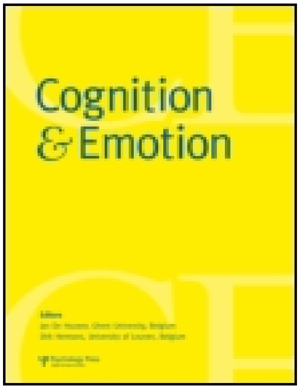

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Hemispheric laterality measured in Rembrandt's portraits using pupil diameter and aesthetic verbal judgements

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Eckhard Hess claimed that pupils dilate to pleasant images and constrict to unpleasant images. However, his work was confounded since his image's luminances and contrasts across conditions were inconsistent. We overcome this limitation and suggest a new, promising methodology for research in this area. We presented rightward or leftward facing male and female portraits by Rembrandt to observers in either their original or mirror-reversed position. Since emotional content may be expressed differently on each side of the face, we used Rembrandt's portraits since most of his males had their right-cheek exposed and females had their left-cheek exposed. This raises questions regarding the emotional and cognitive significance of such biased positioning. Simultaneously, we measured observers pupil size while asking observers to report how (dis)pleasing they found each image. We found that in viewing male portraits pupil diameter was a function of arousal. That is, larger pupil diameter occurred for images rated both low and high in pleasantness. We discuss these findings in regard to the perceived dominance of males and how emotional expressions may be driven by hemispheric laterality.

Keywords: Hemispheric laterality; Pupil size; Face perception; Emotion; Aesthetic judgements.

INTRODUCTION

A novel method to investigate Hess's proposal

Eckhard Hess (1965, 1972), attempted to transform the field of aesthetics by claiming that pupils enlarge when viewing pleasant images and constrict when viewing unpleasant images (see also Fitzgerald, 1968; Goldwater, 1972; Hess & Polt, 1960; Hess, Seltzer, & Shlien, 1965; Simms, 1967). However, pupil size also varies with luminance (Goldwater, 1972; Janisse, 1973, 1974; Kohn & Clynes, 1969; Locher, 1996; Loewenfeld, 1966, 1999; Loftus, 1985; Mannan, Ruddock, & Wooding, 1995; Miller, 1967; Woodmansee, 1966), and since Hess compared images with different intensities and contrast levels, his work was confounded. We overcome Hess's limitations by using a new methodology that compares pupil diameter with verbal reports of pleasantness

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between an original and its mirror-reversed portrait. Using original and mirror-reversed images is a novel technique in that it makes image contrast and luminance irrelevant, since we only compare pupil size across paired-images. Therefore, pupil size differences must be due to variations in observers' perception of an image's emotional content, and not because of differences in their contrast or luminance.

While pupil size may be an indicator of pleasingness this measure is actually more complicated. Influences of the autonomic nervous system on pupil size are not simply a reflection of activation of one branch, and, furthermore, sympathetic arousal can be elicited by more than just pleasingness or, more appropriately, arousing properties of images, and would also include cognitive load (e.g., see Kahneman & Beatty, 1966) as well as a number of other factors that may be less relevant here. Thus, pupil size can be an indicator of a number of environment properties, and the context is likely a driving force in the determinants of pupil size.

Since we used original and mirror-reversed portraits, we were also able to explore the hemispheric laterality of emotional expression. We postulated that Rembrandt may have turned his subject's faces rightward or leftward to display specific emotional content of their facial musculature. For example, self-report assumptions regarding dominance especially of male subjects should show up as emotional responses which might be quantified by pupil size relationships. Thus, we did not set out to disprove Hess, but instead to create a methodology that would re-examine the relationship between a self-report and emotive measure (i.e., pleasantness) and an unconscious physiological measure (i.e., pupil size). As explained in sections below, we found that Hess was incorrect to focus on valence. Instead, he should have focused on arousal, since we found that arousal, not valence, drives pupil diameter for male portraits. Thus, verbal ratings of pleasantness are a self-report measure that we relate to an unconscious indicator of pleasantness (i.e., pupil diameter) as suggested by Hess and others.

Portraiture's leftward bias

Often subjects of portraits expose more of one side of their face than the other side (Grüsser, Selke, & Zynda, 1988; McManus & Humphrey, 1973). For instance, in a study of 1,474 Western European portraits created from the fourteenth to the twentieth century, 891 posers ($\sim$60%) exposed more of their left cheek, whereas 583 ($\sim$40%) exposed more of their right cheek (McManus & Humphrey, 1973). Several portrait studies have verified that this left-cheek asymmetry is stronger in portraits of women (Conesa, Brunold-Conesa, & Miron, 1995; Gordon, 1974; Grüsser et al., 1988). That is, McManus and Humphrey (1973) established that approximately 68% of women's portraits, but only 56% of male portraits have a leftward bias.

While numerous suggestions attempt to explain the portraiture leftward bias (Humphrey & McManus, 1973; Nicholls, Clode, Wood, & Wood, 1999), they often fail to explain the gender difference. One promising interpretation suggests that the leftward bias results from the poser's preference to portray emotional qualities depicted on the left side of the face (Nicholls et al., 1999). Nicholls et al. (1999) instructed participants to pose for a portrait to either "put as much real emotion and passion into a portrait as you can" or "to avoid depicting any emotion at all". In the first case, participants were more likely to turn their left cheek toward a camera during a picture-taking session, whereas in the second case participants were more likely to turn their right cheek toward the camera. Likewise, several studies report that the left side of the face is more intense in exhibiting voluntary emotional expression (Borod & Caron, 1980; Borod, Kent, Koff, Martin, & Alpert, 1988; Nicholls, Ellis, Clement, & Yoshino, 2000; Sackeim & Gur, 1978; Sackeim, Gur, & Saucy, 1978). These findings are consistent with the suggestion that facial expressions are tied to cerebral hemispheric laterality, and that the right hemisphere of the brain is dominant in processing and also displaying emotional expressions (to the left side of the face; Bryden & Ley, 1983).

Given these findings, we speculate that males may not want to portray their emotive left side as much as females (or by the behest of the artist). Likewise, artists may prefer to portray women as being more emotive than men, thereby exposing their left cheek more often. These notions are supported by Grüsser et al. (1988), who examined portraits from the fifteenth to the twentieth century and found a bias for left-cheeked portraits, with the bias always being stronger for female than for male portraits. Thus, we are interested in portrait's left or right sides, not the viewer's preference for a right or left side of an image. This is because our concern is with the hemispheric asymmetry in the encoder (contralateral control of facial musculature) rather than in the perceiver who will produce differences in valence or arousal.

Alternatively, a valence hypothesis suggests that since each cerebral hemisphere controls predominantly the musculature on the lower two-thirds of the contralateral side of the face (Brodal, 1965) each side of the face portrays different emotive qualities. That is, positive emotions should be more prevalent on the right side of the face (since it is governed by the left cerebral hemisphere) and negative emotional expressions should be more prevalent on the left side of the face (since it is governed by the right cerebral hemisphere; Ahern & Schwartz, 1979; Borod, Haywood, & Koff, 1997; Davidson, 1984; Fridlund & Izard, 1983; Gainotti, 1969, 1972; Jasari, Tranel, & Adolphs, 2000; Mandal, Tandon, & Asthana, 1991; Natale, Gur, & Gur, 1983; Rossi & Rosadini, 1967; Sackeim, Greenberg, Weiman, & Gur, 1982; Sackeim & Gur, 1983; Schiff & Lamon, 1989; Schwartz, Ahern, & Brown, 1979; Silberman & Weingartner, 1986; see Powell & Schirillo, 2009, for a literature review). This makes it peculiar that the left cheek is more often portrayed.

Thus, the field of lateralised portraiture has sought to determine whether one side of the face is more pleasant than the other. Schirillo and Fox (2006) showed observers all 373 of Rembrandt's portraits and found that left-cheeked females were assessed as more approachable than right-cheeked females portraits while males portraits (for both sides of the face) were assessed as preferably avoided. Thus, observers were more likely overall to want to approach female rather than male Rembrandt portraits.

Measuring emotional judgements against an unconscious pupil size measure

Research that evaluates facial expressions has been beset with problems (Rinn, 1984). For example, the most popular methodology is to obtain an observer's subjective impression of the stimuli (Russell & George, 1990). This method may cause observers to use separate, immeasurable, criteria in making judgements (e.g., one observer may use an image's contrast, whereas another may use facial features, such as eyebrows). This obfuscates linking aesthetic judgements to cerebral laterality. Thus, it makes sense to try to understand portrait laterality in terms of what may be a related unconscious process.

One measurement that has previously been used as a low-level unconscious indicator of affective processing is pupil size (Hess & Polt, 1960; Janisse, 1974; Loewenfeld, 1999). To circumvent Hess's abovementioned luminance and contrast confounds, we had observers view left- and right-cheeked portraits, *and* their mirror images (e.g., see Figure 1B and 1D), while they determined the aesthetic pleasantness of each image. Simultaneously, we monitored their pupil size allowing us to correlate portrait pleasantness and pupil size. Since original and mirror images have the same luminance profiles, and we only compared pupil size and pleasantness ratings across matched pairs of images, Hess's confounds have been eliminated.

Since Woodmansee (1966) found "significant pupillary constriction with shifts in gaze from darker to brighter areas of the picture" (p. 133), we, like him, presented a blurred image prior to its clear image to minimise changes in pupil size. For example, Figure 1 shows images in their original and mirror-reverse orientation (Figure 1B and 1D) along with their corresponding preceding

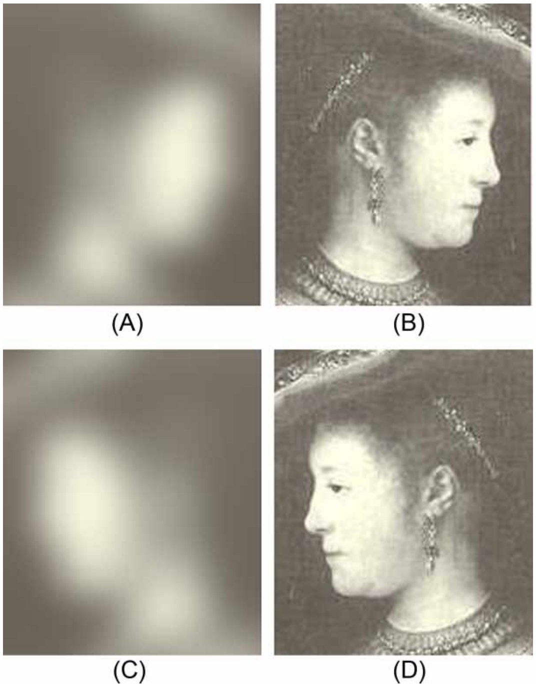

Figure 1. *(A) Blurred original orientation, (B) original orientation of a left-cheeked female, (C) blurred mirror-reverse, and (D) mirror-reverse orientation (A woman in fanciful costume). Baltimore, The Walters Art Gallery (Br. 386). Copyright 1969 Phaidon Press Ltd. Rembrandt, The Complete Edition of Paintings. A. Bredius, revised by H. Gerson.*

blurred images (Figure 1A and 1C). These images are significantly blurred, so that facial pleasantness cannot be extracted from the blurred images (Bachman, 2007).

Valence, arousal and dominance

Our new methodology also allowed us to reexamine earlier works that disagree with Hess's findings, such as Woodmansee's (1967) finding that larger pupil's may occur when presented with unpleasant stimuli. Likewise, Tinio and Robertson (1969) found that unpleasant Thematic Apperception Test cards elicited larger pupil size than control cards and Libby, Lacey, and Lacey (1973) could not define the effective characteristics of those stimuli that produced smaller pupil size. Consistent with these findings is the notion that dominance (typically displayed in males) can lead to larger pupil size (Darwin, 1872). For example, Ellis (2006) speaks of males smiling less due to having more testosterone than females, allowing them to more effectively intimidate rivals. Thus, while the motivation behind our methodology was to overcome Hess's initial confound, what we found was that pupil size is driven by arousal and not valence. We predicted that these arousal differences should only be present in viewing male portraits since they accentuate dominance. This is emphasised in images where each side of the face reflects different emotional expressions, a concept was first posited by Darwin (1872), especially as it relates to dominance.

The use of portraits by Rembrandt allowed us to explore aesthetic judgements of a famous artist while also examining potential differences in facial emotion expression. First, we hoped that using artwork would elicit stronger aesthetic reactions than photographs of faces. Second, prior investigations of Rembrandt's work in the context of hemispheric laterality have shown that perceived dominance is greater when viewing his right-cheeked male portraits leading to the reason for their prevalence (Schirillo, 2000). Thus, we attempt to offer insight into how hemispheric asymmetries may regulate displays of facial emotion, which are reflected by an observer's aesthetic judgement of a portrait. Given that our verbal ratings of pleasingness are a self-report measure, it is of interest to determine their relationship with an unconscious indicator of pleasingness (i.e., pupil diameter) as suggested by Hess and others, and how this in turn might be related to the emotional content of the facial musculature displayed in the images. For example, if self-report interpretations drive assumptions regarding dominance, they may show up in the portraits' emotional qualities, which are reflected in pupil-size relationships.

MATERIALS AND METHOD

Subjects

Twenty-eight right-handed observers (12 males; ages 18–22) with normal or corrected-to-normal vision (but no eyeglasses) from the introductory psychology research pool at Wake Forest University participated in the study. The study was performed in accordance with the ethical standards of the Declaration of Helsinki.

Stimuli

Twenty black and white images taken from oil paintings were chosen from a collection of 373 portraits painted by Rembrandt. The specific portraits chosen represent his most rightward and leftward facing portraits (Schirillo & Fox, 2006). Greyscale images were used instead of coloured images because colour can lead to changes in pupil diameter (Kohn & Clynes, 1969; Miller, 1967). Five were right-cheeked males (two were self-portraits by Rembrandt), 5 were left-cheeked males, 5 were right-cheeked females, and 5 were left-cheeked females (the appendix lists painting names). Next, these images were used to produce 20 mirror-reversed images using PhotoShop IBM. The portraits were only of busts. Each portrait was scanned into PhotoShop and was projected to each observer individually using an IBM CRT computer monitor using Microsoft PowerPoint. Viewing distance was 24″ making the image size range from 11.7° (height) $\times$ 8.5° (width) to $11.8^\circ \times 12.4^\circ$. The close viewing distance to the screen limited observers' ability to spend considerable time off-screen. To verify this notion, since the head-mounted Applied Science Laboratories (ASL; series 6000) eye-tracker could also measure eye position, we determined that observers were only off-screen approximately 3% of their total viewing time. Our data also showed that time with no record (due to eye closure) was minimal. In addition, forty blurred images were created (20 from original and 20 from mirror-reversed images) in PhotoShop using a Gaussian blur function (see Figure 1). There was no ambient lightning in the experimental chamber, in that it was a room without windows. Since the door was closed, the only light available came directly from the computer screen that showed the images.

The eye-tracking device was used to determine the pupil size of the left eye. The right-eye pupil size was not measured because pupil size is believed to be conjugate across the two eyes (Loewenfeld, 1999). Pupil diameter was recorded automatically every 17 ms for each entire 15-second trial. The average size across the entire 15-second viewing period was computed minus any time the pupil computation was off-line (due to blinks, etc.). Given that the ASL eye-tracker stops recording when the eye closes more than 50% (assumedly due to blinks or partial eye closure) we have no record of this data.

Instead of using linear interpolation to estimate the pupil size during this off-line period (Steinhauer, Siegle, Condray, & Pless, 2004), we felt it best to simply eliminate these segments from our dataset since blinks can alter pupil size (Nakayama, 2006). Given that the ASL eye-tracker is fixed to the head, head movements did not alter pupil diameter recordings or result in loss of tracking. Thus, other than eye-blink time we did not remove any artefacts from the data, except that one observer's data was excluded entirely from the data set because of abnormal tonic resting diameter (Verney, Granholm, & Dionisio, 2001). The remaining data were imported into Excel to do the data cleaning and then converted to SPSS to do the statistical analysis. Average pupil size was calculated for each image across the observation period, which excluded instances where the observer blinked or had partial eyelid closures (since when the eye closes the ASL machine cannot record any pupil size). Observers used a chinrest to ensure a fixed 24″ distance between themselves and the screen to retain a constant depth of field across the images (Simms, 1967).

Observers viewed twenty images in their original posed orientation, and in their mirror-reversed orientation (resulting in 40 images in total). Since we only compared pupil size across original versus mirror-reversed images, our within-subject's design eliminates potential confounding factors such as age and medication. Right-cheeked mirror-reversed images are portraits that originally faced rightward but due to reversal appeared to be of original left-cheeked images. Likewise, left-cheek mirror-reversed images appeared to be of original right-cheek portraits. Images were randomised, and presented to each observer in the same random order. Each of the 40 images was viewed for 15 seconds and was preceded by a blurred version of the image for 15 seconds. Fifteen seconds was decided upon because of three previous findings. First, Smith and Smith (2001) found that art viewers examined The Metropolitan Museum of Art paintings for a median of 17 seconds. Second, Aboyoun and Dabbs (1998) showed that pupil size rapidly decreases upon image presentation, which then recovers to either baseline or above baseline levels. Consequently, pupil size must be measured for at least several seconds to overcome this initial depression. Lastly, Richer, Silverman, and Beatty (1983) found that pupil size increases begin about 1.5 seconds before stimulus presentation and peak around a second after presentation. As a result, we gave observers more time than needed to generate an entire response to an image. Observers' pupil size was measured during each non-blurred image presentation while they contemplated how pleasant they found the non-blurred images. Observers were instructed to think about the aesthetic pleasingness of each image for the entire 15 seconds it was shown and then report their judgement after the image was removed. This occurred during the presentation of the subsequent blurry image.

The rationale for presenting a blurred image of a given portrait prior to presenting that portrait was to avoid the following confound prevalent in the pupillometry literature. That is, if a constant blank grey screen was used as a baseline the subsequent test image would produce the following effect (see Figure 2, taken from Bradley, Miccoli, Escrig, & Lang, 2008). That is, the most important natural function of the pupil is to dynamically respond to changes in environmental illumination with an initial constriction (i.e., the light reflex) that is related to stimulus luminosity (Beatty & Lucero-Wagoner, 2000). Thus, if a constant blank grey screen were used as a baseline the brighter images would produce a larger constriction than the dimmer images. This effect takes up to 6 seconds before reaching a plateau. To circumvent this effect we choose to first present for 15 seconds a blurred image of the subsequent test portrait. This does two things. First, it makes the large constriction (i.e., light reflex) occur during the blurred image rather than during the test image. By the end of the 15 seconds of viewing the blurred image the pupil has adjusted to the light level of the image that will subsequently be presented. Given this very long duration the pupil will no longer carry over any information from the previous clear portrait. This is because the pupil is reflexive and does not contain a memory loop so by the end of presenting a blurred image there are no residual effects from the proceeding clear image. However, the blurred images differ in luminance thus setting a different baseline for the subsequent portrait. This is actually desired, so that the magnitude of the effect is not the result of a shift in overall luminance level (as occurs in Figure 2). Instead, each original and mirror-reversed blurred image sets the same baseline for their subsequent clear image. This is important since it is *only* the results of these two (original and mirror-reversed test image) pupil diameters that will be compared against each other.

We manually recorded pleasantness scores for each image by taking verbal aesthetic judgements using a 1–9 numerical scale, with one meaning *most displeasing*, five meaning *neutral*, and nine meaning *most pleasing*. Pleasingness is just one dimension of aesthetics, but seemed to be appropriate based on a study that used five evaluative scales (e.g., pleasingness, likeability, preferability, interestingness, and complexity; Russell George, 1990). In Russell and George's (1990) study, pleasingness was highly correlated with likeability and preferability, and was the highest in inter-subject agreement. The difference in verbal rating between the original and mirror-reverse images was then correlated with the difference between the average pupil diameters.

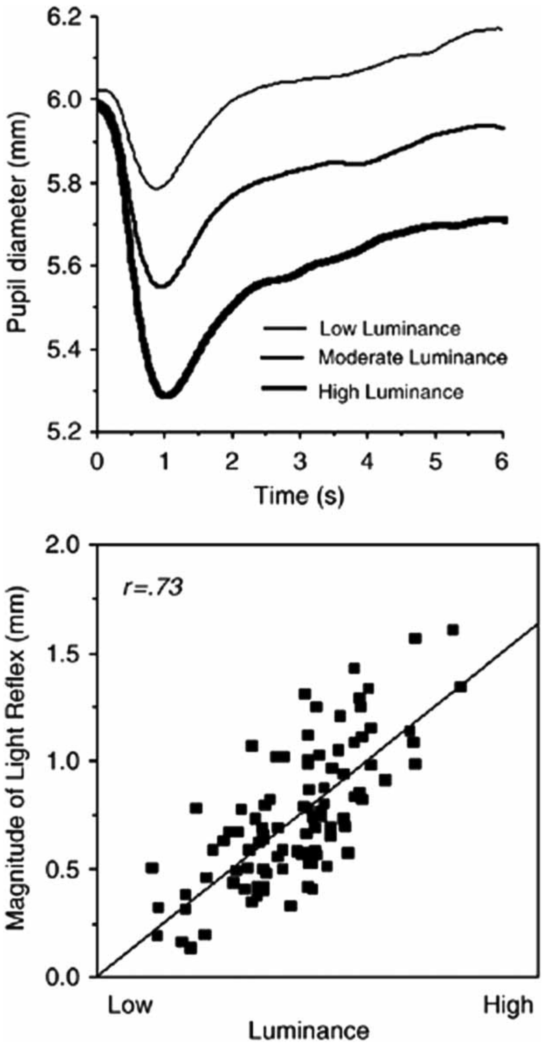

Figure 2. *(Top) Average pupil diameter over time as a function of luminance of the image viewed. This variation is termed the light reflex. (Bottom) correlation of the magnitude of the light reflex as a function of image luminance (taken from Bradley, Miccoli, Escrig, & Lang, 2008).*

Following the stimulus presentation, observers were administered a questionnaire that pertained to their art training and their familiarity with the portraits. They were not told prior to the experimental session that they would see original and mirror-reversed images, but they may have become aware of this as the session progressed. To determine if observers noticed these mirror duplications, we asked whether they noticed anything unusual about the images at the end of the session. Ten of 28 observers reported noticing that a number of images were mirror-reversed. Only one observer had formal art training and six reported that they had seen less than 25% of the portraits before. Thus, while many of these images are famous, most observers were not familiar with them.

RESULTS

Pleasantness ratings

Before examining individual pleasantness ratings, we obtained each observer's average pleasantness ratings for each of the eight portrait types (e.g., original right and left, mirror-reverse right and left, males and females). This resulted in each observer having eight data points. Then, pleasantness ratings for male and female portraits were submitted to a 2 (Portrait Gender: male vs. female) $\times$ 2 (Orientation: original vs. mirror-reversed) $\times$ 2 (Side of Face: left vs. right) repeated-measures analysis of variance (ANOVA). Males and female observers were not included as a within-subjects factor because the present design lacked sufficient power.

Figure 3 shows the means for each portrait group. There was a main effect for Side of Face with left-cheeked rated higher than right-cheeked individuals, $F(1, 27) = 9.55$, $p = .005$. Additionally, there were three significant interactions. First, there was a Side of Face by Orientation interaction, $F(1, 27) = 14.58$, $p = .001$. While left-side portraits (original and reversed) were rated higher than right-side portraits (see Side of Face main effect), right mirror reversals were rated higher than right originals ($M = 4.30$ vs. $M = 4.19$), while left originals were rated higher than left mirror reversals ($M = 4.62$ vs. $M = 4.44$, respectively). That is, leftward appearing portraits, left originals and right reversals whose appearance to the observer seems to be left faced, were rated higher than right-faced originals and left mirror

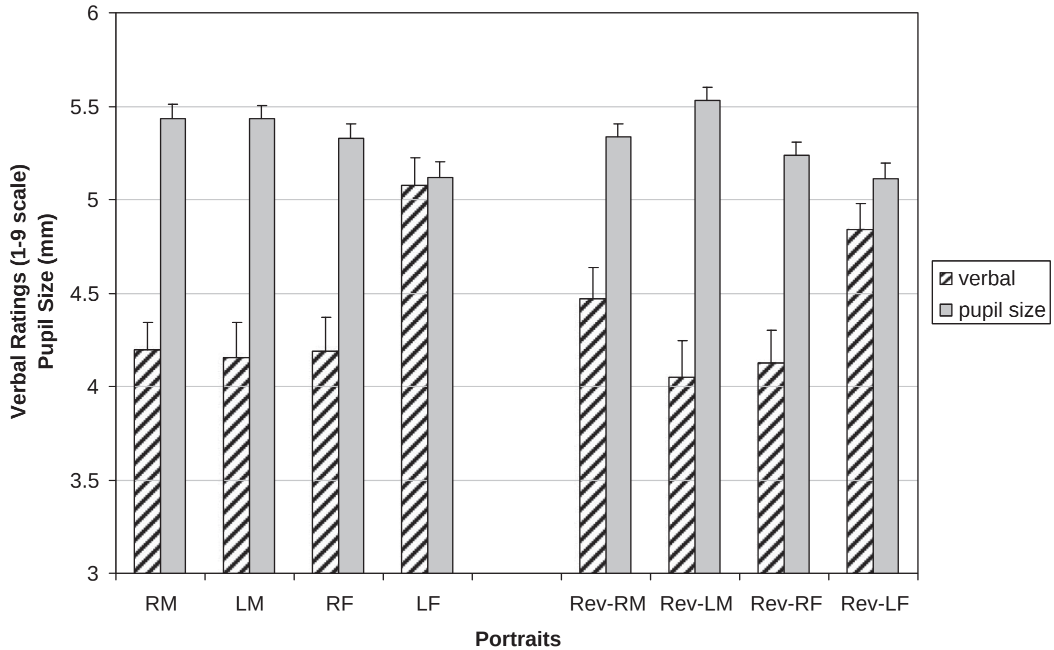

Figure 3. *Verbal ratings (striped bars) as a function of portrait type on a 1–9 scale, with 1 indicating most displeasing, 5 indicating neutral and 9 indicating most pleasant. Pupil size in mm (solid bars) as a function of portrait type (R = Right-cheeked, L = Left-cheeked, M = Males, F = Females, Rev = Mirror-reversed images). Error bars = SEM.*

reversed (portraits viewed as seemingly right faced). Second, a Side of Face by Portrait Gender interaction was found, $F(1, 27) = 14.03$, $p = .001$, with left-side female portraits rated higher than right-side female portraits ($M = 4.96$ vs. $M = 4.16$), whereas the opposite is true for male portraits, though to a lesser degree ($M = 4.10$ for left male portraits and $M = 4.33$ for right male portraits). Third, there was a Portrait Gender by Orientation, $F(1, 27) = 9.04$, $p = .006$, such that female mirror reversals were rated lower than original female portraits ($M = 4.48$ vs. $M = 4.63$), whereas the opposite relationship was found for males ($M = 4.26$ vs. $M = 4.17$).

Next, we conducted two comparisons to determine whether there was an observer bias to prefer portraits with cheeks displayed predominantly in the observer's left or right field of vision. To determine if there was a left hemispace bias, a comparison was made between the pleasantness ratings of left-cheeked females and reversed orientation right-cheeked females (i.e., those exposing their right cheek as if it were their left cheek). Likewise, to determine if there was a right hemispace bias a comparison was made between the pleasantness ratings of right-cheeked females and reversed left-cheeked female portraits (i.e., those exposing their left cheek as if it were their right cheek). There was a significant difference between judgements of left-cheek original and reversed orientation right-cheeked female portraits, $F(1, 27) = 26.68$, $p < .001$, and between right-cheek original female portraits and reversed orientation left-cheeked females, $F(1, 27) = 14.08$, $p < .001$, which suggests that there was no hemispace bias.

Pupil size

Since the images were presented in random order, either an original or reversed image could appear first. A test was conducted to compare the average pupil diameter between an image's first and second presentation. For this analysis, we used a generalised estimating equation (GEE; Liang

& Zeger, 1986) approach to account for the correlation of responses within viewers. GEEs estimate the within-subject similarity of the residuals, which is then used to estimate the regression parameters and calculate standard errors (Hanley, Negassa, Edwardes, & Forrester, 2003). GEEs extend the use of the generalised linear model to estimate parameters and are considered to obtain more efficient and unbiased regression parameters than a standard linear regression because they adjust the covariance matrix of the estimated parameters to account for the non-independent nature that occurs across observations (Ballinger, 2004; Zorn, 2001). In order to have just one outcome variable, we took the pupil difference between the two presentations, which represents the change in pupil size from the first presentation to the second presentation. An intercept only model was fitted and analysed. If one presentation impacted pupil size more than the other, then we would expect the intercept to be statistically significantly different from zero. However, the results of the test failed to provide evidence for the suggestion that the presentation of the image impacted pupil size, Wald chi-square = 0.743, $p = .389$. Thus, it was not during the second presentation (where surprise might have occurred) that pupil size got larger (i.e., arousal occurred). However, there may have been an anticipatory response to all of the images. Unfortunately, we did not record pupil diameter during the preceding blurred images (since we used a within-subjects design and therefore did not need baseline responses). Even so, there should be no difference in anticipation between an original and mirror-reversed image in that all images were presented in random order.

Before examining individual pupil size, we obtained each observer's average pupil size for each of the eight types of portraits. Mean pupil sizes for these groups are shown in Figure 3 alongside the means of the previous three-way ANOVA conducted for verbal pleasingness. There was a main effect of Portrait Gender across the eight types of portrait, $F(1, 27) = 35.64$, $p < .0001$ (Figure 3). Average pupil diameter when viewing male portraits was larger ($M = 5.4$) than when viewing females portraits ($M = 5.2$). This analysis also yielded a significant Side of Face × Orientation interaction, $F(1, 27) = 12.72$, $p = .001$. Original right-cheeked portraits ($M = 5.38$) elicited greater average pupil size than right-cheeked reversed portraits ($M = 5.28$). Conversely, average pupil size was largest for left-cheeked reversed portraits ($M = 5.32$) than for original left-cheeked portraits ($M = 5.28$). When these findings are examined alongside the Side of Face × Orientation interaction for verbal ratings, we find that images with the appearance of being right cheeked yielded larger average pupil size and lower verbal ratings.

Overall, pupil diameters were well within the normal range, where, as expected, the luminance of the portrait viewed dramatically affected pupil size (Figure 4; range = 4.78 mm to 5.79 mm). The fact that pupil contraction increased with an increase in image luminance reinforces our decision to use mirror-reversed images.

Linear and quadratic relationships between pleasantness ratings and pupil diameter

We examined linear and quadratic relationships between pleasantness and pupil size. First, a regression was computed to examine whether there was a linear relationship between pleasantness and pupil diameter. This was done by taking each portrait (original or mirror reversed) for each observer as an individual case. Then

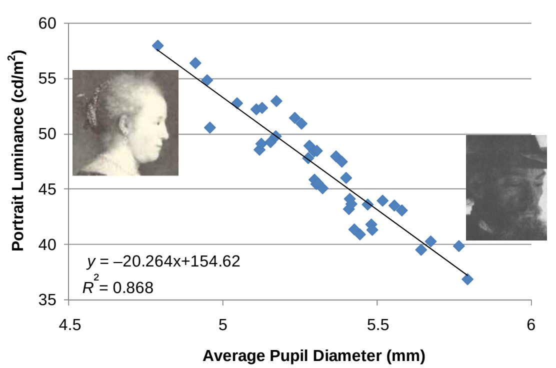

Figure 4. *Correlation between pupil diameter given the average luminance for each portrait (n = 28 observers). The figure includes the portraits with the highest and lowest average luminance.*

difference scores between verbal pleasingness were regressed using the predictor variables of pupil size difference and quadric pupil size difference. Figure 5A shows that, for males, as the original verbal ratings became more positive (represented on the x-axis by verbal rating differences that were greater than zero), the original pupil size got smaller. Likewise, as original ratings became more negative (represented on the x-axis by verbal rating differences that were less than zero), the original pupil size got larger. This negative slope was statistically significant for male portraits, $r(278) = -.16$, $p < .006$ (Figure 5A), but we failed to find a relationship for female portraits, $r(278) = -.04$, $p = .466$ (Figure 5B). This means that when an original male portrait was preferred (whether right or left cheeked) the pupil was smaller while viewing the original portrait compared to the mirror-reversed image. Yet, when the mirror-reversed portrait was preferred (whether right- or left-cheeked) the pupil was smaller while viewing the mirror-reversed portrait compared to the original.

Next, linear and quadratic functions were entered into a regression model to evaluate if the relationship is better categorised by a quadratic function. The following quadratic regression model was computed separately for male and female portraits:

$$pupil = b_0 + b_1(pleasantness) + b_2(pleasantness^2)$$

Figure 5A shows that there was a significant quadratic effect for male portraits, $b = 0.40$, $t(277) = 3.22$, $p = .001$, when the linear relationship was held constant. Pupil diameter was largest when there were the greatest differences in verbal ratings between an original and mirror-reversed male image. That is, when images were extremely liked or disliked, pupil size increased. This quadratic relationship accounted for significantly more of the variance than the linear relationship, $\Delta R^2 = .04$, $p < .001$. However, for female portraits, the regression model failed to find a significant linear or quadratic relationship between pupil diameter and pleasantness, $F(2, 277) = 0.59$, $p = .56$ (Figure 5B). Since each observer viewed multiple portraits, we examined whether the data were potentially clustered at the level of the observer. Therefore, we explicitly modelled between-cluster variation as a random effect by fitting our data within a multilevel model. If the data were clustered by observer, we would expect the covariance parameter estimate between observers to account for some portion of the total variance. However, the attempt to fit a multilevel model failed to reveal clustering by observer for our outcome variable because the estimated variance between observers was negative. As a result, this random effect was removed from the model.[1] Pupil size could be confounded by the luminance of an image, so difference scores were calculated to compare across images. If difference scores were not used, and instead, pupil size for original and mirror-reversed images were used in the regression, then our findings would be seriously confounded because these values do not account for the changes in luminance/contrast across images and comparisons across images would be misleading. In sum, there were 560 total cases, i.e., 28 observers × 20 portraits(original - mirror-reversed), used in the analysis.

Outcome (DV) variable = pupil difference

Predictor (IVs) variables = verbal rating difference; quadratic verbal difference

It is important to realise that our images were not necessarily less pleasing in their non-original orientation. Instead, what we found was that only if there were a large difference in the rating between original and mirror-reversed images (where either orientation could have been the more pleasing image) there would also be a large difference in pupil size between those images.

[1] The estimated variance covariance matrix (G matrix) of the random effect of viewer is not positive definite, which meant that the between-subjects variation component being estimated was negative. Since it is not possible to have a negative variance, SAS automatically set the negative variance estimates to zero.

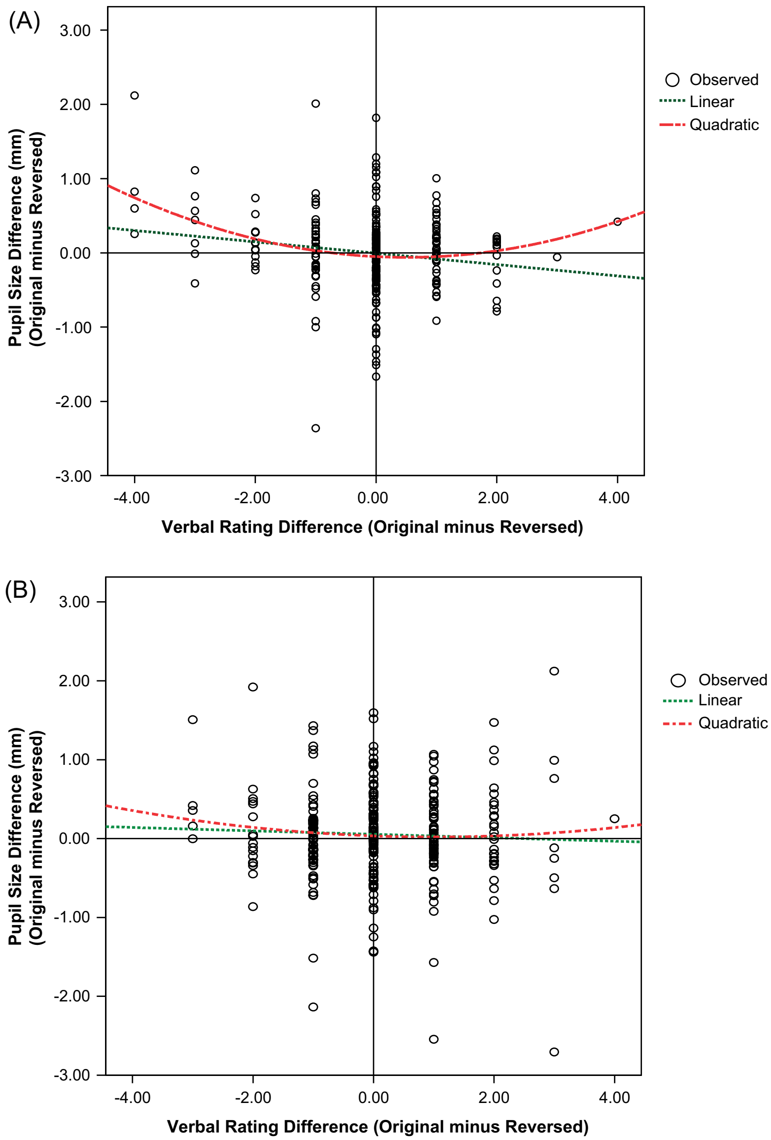

Figure 5. *Pupil size difference score (original minus mirror-reversed) as a function of the difference in 1–9 verbal rating scores (between an original minus mirror-reversed image) for all (A) male portraits (B) female portraits.*

Since pupil size is an indicator of pleasantness, when verbal report differences are zero, pupil size differences should also be zero. Consistent with this assumption, we failed to find the intercept to be significantly different from zero for either males portraits, linear: $t(227) = -0.15$, $p = .88$; quadratic: $t(227) = -1.50$, $p = .14$, or female portraits, linear $t(227) = -0.04$, $p = .47$; quadratic: $t(227) = 0.76$, $p = .45$.

As expected, there were almost as many zero differences between original and reversed-image verbal ratings as there were difference scores

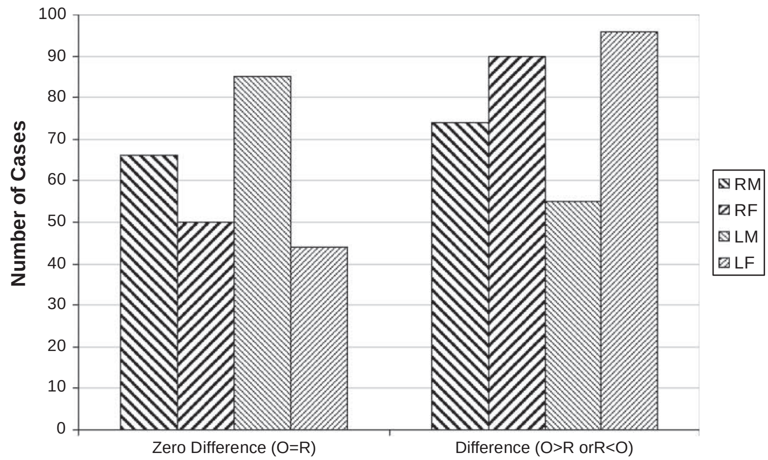

Figure 6. *Number of cases for all observers in which there was either a zero difference in verbal rating or there was a difference of any magnitude—with the original score being either more or less than the mirror-reversed image. (R = Right-cheeked, L = Left-cheeked, M = Males, F = Females.)*

(Figure 6). This inevitable outcome can potentially affect any of our linear and quadratic relationships.

Potential fatigue

Woodmansee (1966) found that arousal decreases over the course of an experiment. Thus, we checked to see if fatigue occurred over the course of an experimental session. Observer's pupil size and verbal judgements did not systematically change across the experimental session, $n = 40$ trials, $r(1117) = -.05$, $p = .13$ and $r(1117) = -.04$, $p = .17$, respectively. However, observers' pupil size variability (i.e., standard deviation) increased over the course of the experiment, $r(1117) = .15$, $p < .001$, suggesting that observers were, in fact, becoming increasingly fatigued over the 40 trials.

A second indicator of fatigue is blink rate, which is associated with cognitive load (Stern, Walrath, & Goldstein, 1984). We examined this by determining the percentage of time a corneal reflection was absent. Observers had their eyelid closed, on average, 11% ($SEM =$ 0.04%) of the time. That means, on average, observers blinked between 11.4 and 33 times per 20-second trial, which amounts to 2.2 seconds. This blink rate increased across the 40 trials, $r(1117) = .25$, $p < .001$. Importantly, pupil diameter variability and blink rate did not co-vary with the dependent variables of pupil diameter or verbal judgements.

DISCUSSION

While it has been shown that pupils get larger to intense (arousing) stimuli, we only replicated this for male portraits. Schirillo's (2000) analysis of Rembrandt's portraits suggests this may be because the perceived dominance of male portraits was rated higher than for female portraits. Dominance may be associated with positive (e.g., self-assurance, arrogance, and feeling bold or triumphant) or negative affective states (e.g., hostility, irritability, and anger; Demaree, Everhart, Youngstrom, & Harrison, 2005). It is possible that while Rembrandt painted males to exhibit these positive dominant traits (see Humphrey & McManus, 1973), negative dominance traits may have also been captured. Thus, the negative linear relationship between pleasantness ratings and pupil diameter for males is consistent with Tinio and Robertson (1969), who found that aggressive Thematic Apperception Test cards elicited larger pupil size than control cards. This implies that Rembrandt's male portraits may actually be perceived as domineering, which is consistent with Libby et al. (1973) and Woodmansee (1967), who found that unpleasant images were associated with larger pupil sizes compared to pleasant images.

Given that our verbal ratings of pleasingness are a self-report measure of what may be an emotive expression, it was of interest to determine their relationship with an unconscious indicator of pleasingness (i.e., pupil diameter) as suggested by Hess and others, and how this in turn might be related to the emotional content of the facial musculature displayed in the images. For example, self-report assumptions regarding dominance can be present in the emotional qualities of the portraits, which is captured by pupil size relationships. We have explored these variables while simultaneously eliminating Stern and Strock's (1987) concern that one drawback to pupillometry is that changes associated with such variables are considerably smaller than those associated with illumination effects.

This new methodology eliminates Hess's fluctuations in luminance and contrast across images allowing us to observe how pupil size varies as a function of the differences in verbal reports of pleasant and less pleasant original and mirror-reversed portraits. This was done by *only* comparing measurements between original and mirror-reversed images, which makes image contrast and luminance irrelevant. This also means we do not require a baseline pupil size from the blurred images; since pupil size should not vary between original and mirror-reversed images because such images do not vary in image contrast and luminance. If they do differ, this must be because the emotional content of the images vary, not their image contrast or luminance.

Given that it is impossible to equate apparent contrast or mean luminance across images, research testing Hess's hypothesis had ceased. However, our improved methodology does not need to equate apparent contrast or mean luminance since this automatically occurs by comparing pupil size only across an original and its mirror-reversed image. In essence, we created a methodology that re-examined the relationship between a self-report and emotive measure (i.e., pleasingness) and an unconscious physiological measure (i.e., pupil size). We show that Hess was incorrect by focusing on valence. Instead he should have focused on arousal, since arousal drives the effect for male portraits not valence.

Male portraits showed both a linear and quadratic relationship between pupil diameter and aesthetic judgements of pleasantness. The linear model indicates that pupil diameter increased when viewing negative male portraits and decreased when viewing positive male portraits, whereas a quadratic model shows that pupil diameter increases to both highly pleasant and unpleasant male portraits. Thus, it is plausible that researchers who used only a linear function found that unpleasant images were associated with larger pupil sizes compared to pleasant images (Libby et al., 1973; Tinio & Robertson, 1969; Woodmansee, 1967). These findings do not support Hess's (1965) prediction, which suggested that unpleasant images would have been associated with a smaller pupil diameter.

However, a quadratic relationship accounts for significantly more variance than a linear relationship. In this case, pupil size increased with large differences among pleasantness ratings for male portraits. This is consistent with previous findings that pupil size is related to stimulus intensity rather than its specific positive or negative content (Aboyoun & Dabbs, 1998; Janisse, 1973, 1974, 1977). For example, arousing situations have been shown to produce larger pupil diameter in non-visual stimuli studies. Nunnally, Knott, Duchnowski, and Parker (1967) found that painfully loud sounds increased muscle tension causing larger pupil size. They also found an increase in pupil diameter when observers expected to hear a gunshot. Likewise, Polt (1970) found larger pupil size during mental arithmetic tasks when observers believed they would be shocked for incorrect answers.

Though observer's pupil size (Kahneman & Peavler, 1969) and verbal judgements did not change systematically over the experimental session, pupil size variability did increase. Likewise, eye-blink frequency increases as observers become increasingly fatigued (Fukuda, Stern, Brown, & Russo, 2005; Stern, Boyer, & Schroeder, 1994; Stern & Strock, 1987), which was also found in the present study as the experiment progressed. These findings suggest that fatigue may have increased over the 40 trials. However, since images were randomly arranged, there was no correlation between these possible fatigue effects and the dependent measures of pupil size and verbal ratings.

The aesthetic verbal pleasantness judgements suggest that the observers were attending to the actual facial physiognomy of the posers and that pleasantness was determined to a lesser degree by the orientation the portrait faced. In agreement with prior research (Schirillo & Fox, 2006), the left sides of women's faces were rated as more aesthetically pleasant than their right sides. This suggests that for women it is important to express more emotive facial qualities than males, in agreement with Nicholls et al. (1999) and the right-hemisphere model of emotion lateralisation. Yet, how emotion may be lateralised in the cerebral hemispheres is still under debate (Davidson, 1995; Demaree et al., 2005; Killgore & Yurgelun-Todd, 2007). One recent argument is that an approach/withdrawal model may provide a more appropriate fit to the data as opposed to the positive/negative hemispheric difference model (Demaree et al., 2005). Davidson and others' interpretation of the left/right differences in emotion valence is that the right cerebral hemisphere regulates withdrawal behaviours whereas the left cerebral hemisphere regulates approach behaviours (Davidson, 1984, 1992, 1995; Davidson, Ekman, Saron, Senuluis, & Friesen, 1990; Fox, 1991; Kinsbourne, 1982). If this is the case, as stated in Schirillo (2000), we speculate that Rembrandt preferred to paint females left side because it captured the attractive quality of being demure.

In summary, this study provides a new methodology to research the association between pupil diameter and aesthetic verbal judgements. Based on its findings, Eckhard Hess's (1965, 1972) hypothesis that pupils dilate to pleasant images and constrict to displeasing images seems incorrect. Instead, at least for male portraits, pupil size is a function of arousal such that pupil size difference increases when the difference in verbal reports are both most pleasant and most displeasing. We consider the possibility that this is related to perceived dominance (Ellis, 2006), in that a linear function showed that images rated low in aesthetic pleasantness evoked the largest pupil diameter. We consider the possibility that this is related to disliking perceived threat (Darwin, 1872), which may have been a dominance trait that Rembrandt inadvertently depicted.

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APPENDIX

Listing of painting titles (taken from Bredius, 1969)

Left-facing females

1. Rembrandt's Sister, 1632. Stockholm, Nationalmuseum (Br. 85)
2. Saskia. 1643. Cassel, Gemaldegalerie (Br. 101).
3. Saskia. 1636. Hartford, Connecticut, Wadsworth Atheneum (Br. 105).
4. Hendrickje Stoffels as Flora .1654. New York, Metropolitan Museum of Art (Br. 114).
5. Amalia van Solms .1632. Paris, Musee Jacquemart-Andre (Br. 99).

Right-facing females

1. Rembrandt's Mother as a Biblical Prophetess (Hannah?). 1631. Amsterdam, Rijksmuseum (Br. 69).
2. Saskia. 1633. Washington, National Gallery of Art (Widener Collection) (Br. 96).
3. Rembrandt's Sister. 1634. Indianapolis, John Herron Art Museum (Br. 100).
4. A Woman in Fanciful Costume. 1648. Baltimore, The Walters Art Gallery (Br. 386).
5. A Young Girl Seated. 1660. London, E. S. Borthwick Norton Sale, 15 May 1953 (Br. 393).

Left-facing males

1. Head of an Old Man. Copenhagen, Statens Museum (Br. 136).
2. A Man in Oriental Costume. 1633. Munich, Alte Pinakothek (Br. 178).
3. A Bearded Man .1646. Cassel, Germaldegalerie (Br. 230).
4. Study of an Old Man. 1640. Detroit, Mrs Standish Backus (Br. 244).
5. Portrait of an Old Man in a Pearl-Trimmed Hat. 1662. Dresden, Gemaldegalerie (Br. 324).

Right-facing males

1. Self-Portrait. 1629. Munich, Alte Pinakothek (Br. 2).
2. Self-Portrait. Not dated. The Hague, Mauritshuis (Br. 24).
3. An Old Man with a Gold Chain. 1630. Los Angeles, Hans Cohn (Br. 149).
4. Portrait of a Man Reading. 1645. Williamstown, Massachusetts, The Sterling and Francine Clark Art Museum (Br. 238).
5. Study of the Head of an Old Man. 1661. New York, John Hay Whitney (Br. 261).