Matching reality in the arts: Self-referential neural processing of naturalistic compared to surrealistic images

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Abstract. How are works of art that present scenes that match potential expectations processed in the brain, in contrast to such scenes that can never occur in real life because they would violate physical laws? Using functional magnetic resonance imaging, we investigated the processing of surrealistic and naturalistic images in visual artworks. Looking at naturalistic paintings leads to a significantly higher activation in the visual cortex and in the precuneus. Humans apparently own a sensitive mechanism even for artistic representations of the visual world to separate the impossible from what potentially matches physical reality. The observation reported here also suggests that sensory input corresponding to a realistic representation of the visual world elicits higher self-referential processing.

1 Introduction

Humans have an apparently innate need for coherent and continuous perceptual experiences (Spelke 1994), usually anticipating a confirmation of what is to be expected when visual stimuli are processed (Gibson 1966; Epstein 1985; Klinger 1998; Heine et al 2006; Steger et al 2008). For a long time now, it has been hypothesised that the construction of visual stability, the search for coherent experiences, and the extraction of the meaning of visual stimuli depend on a match of expectations and sensations (Helmholtz 1896). The reafference principle (Holst 1954), or the concept of corollary discharge (Teuber 1960), has been suggested to explain why we experience the world stable even though visual input on the retina is never static; an anticipatory process takes place by comparing centrally the position of a new target (the reafference) with the efference copy of a programmed saccadic eye movement. In more general terms, stored representations of the visual world and genetically determined frames of reference constitute how we expect the world to be. Thus, unlike a sensation-based bottom–up analysis of visual information, a concept-based top–down complementary activity provides a semantic frame for what we are going to see (Zeki 1999; Pöppel 2005). These complementary processes can also be referred to in a very practical sense (Tanida and Pöppel 2006) as "surprise perception", referring to responses of stimuli that cannot be anticipated, and "support perception", referring to responses of stimuli which are expected, the latter contributing to the construction of positional and conceptual stability.

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Anticipatory perception is embedded within an attentional network. As attentional processes play a functional role in predicting the location of future percepts (external) as well as in controlling top–down processing (internal) (Egeth and Yantis 1997; Bao and Pöppel 2007; Chun et al 2011), it can even be argued that attention evolved out of the need for visual stability (Godijn and Theeuwes 2003). Additionally, a temporal integration mechanism is necessary to construct perceptual identity. It has been demonstrated empirically that a pre-semantic temporal integration mechanism lasting up to approximately 3 s can serve as a temporal platform or a temporal window to create and to maintain perceptual identity (Pöppel 2009, 2010; Pöppel et al 2011).

On the basis of the invariant structure of objects (Gibson 1966), we are usually able to perceive the world as coherent and stable in a way as if reality is reflected (Gibson 1967). However, this potential match does not apply to stimuli that cannot occur in real life. Visual recognition of familiar versus unfamiliar images has been widely investigated, and functional imaging studies could provide some insights into neuroanatomy, neurophysiology, and modularity of the recognition process (Kanwisher et al 1996). To further investigate the difference in visual processing of something that is consistent with perceptual expectations and something that is perceptually impossible, we conducted a study in which we used high field functional magnetic resonance imaging (fMRI) with stimuli representing naturalistic and surrealistic paintings, determining whether this differentiation applies to artistic representations. While naturalistic paintings present the world in a habitual way, surrealistic paintings violate the expected frame of reference. Surrealistic paintings are characterised by presenting mainly recognisable objects but in constellations that do not exist in real life or that are impossible from a physical point of view. In presenting impossible scenes, these artworks prevent an effortless processing of information to come to a meaningful interpretation of the visual world. This processing fluency is proposed to be a main moderator of aesthetic experiences (Leder et al 2004; Reber et al 2004). On a behavioural level it could already be shown that surrealistic art may elicit negative reactions due to a lack of directly accessible meaning (Proulx et al 2010). We hypothesised that percepts violating an expected percept cannot be integrated effortlessly into a frame of prior experiences or expectations and therefore also lack the potential for self-reference. As it has been assumed that cortical midline structures refer to such self-representations (Han and Northoff 2008), we expected naturalistic and surrealistic paintings to have different activations in these areas.

2 Method

2.1 Participants
Fifteen right-handed subjects (seven male; mean age 26 ± 4 years) with normal or corrected-to-normal vision participated. The study was conducted in accordance with the Declaration of Helsinki and approved by the ethics committee. Informed consent was provided, and subjects received financial reward. All participants reported visiting an art museum less than two times per year. Thus, they were considered not to have expert knowledge of the visual arts.

2.2 Materials
100 surrealistic and 100 naturalistic pictures have been evaluated by twenty-five subjects in a pilot study on a 5-point Likert scale on the dimensions valence (positive or negative value), arousal (intensity of the triggered emotion), and familiarity. Extremes and pictures of high familiarity were excluded, leaving 40 pictures in each category. From these, 8 were chosen per category (naturalistic/surrealistic) matched in values on all three dimensions (see supplemental material, figure S2, at http://dx.doi.org/10.1068/p7191). Homogeneous colour fields served as control stimuli. All pictures had the same image area and were equalised in luminance.

We further compared paintings of the two conditions in several psychophysical parameters. With respect to image-luminance-related parameters, we calculated the saturation of colours, defined by a combination of light intensity and distribution across the spectrum of different wavelength, and values for colour channels in RGB colour space. Moreover, spatial-frequency-related parameters were calculated. Fourier analyses were conducted for each painting. As a measure for the overall power of Fourier components in the spatial domain, the amplitude was computed by summing all the coefficient amplitudes of each Fourier basis. To analyse the power of frequencies separately, we first divided the spatial domain into high- and low-frequency components, computed by the sum of coefficient amplitudes of the Fourier bases whose frequencies are above 73% or under 27%. Frequency components were both measured in horizontal direction (W) and in vertical direction (H). In addition, intensity gradient statistics were computed to tell the global structural information of every painting. Therefore, parameters for intensity gradient magnitude and skewness and kurtosis of pixel gradient orientations were computed by the norm of gradient at each pixel. There were no significant differences between the two painting categories (table 1).

Table 1. Statistical comparison for image characteristics of naturalistic versus surrealistic paintings.

Characteristic	M_N	SD_N	M_S	SD_S	t	p
Image-luminance-related parameters						
Luminance	116.34	22.39	104.65	21.45	1.07	0.31
Saturation	0.32	0.12	0.28	0.16	1.07	0.60
Red	125.57	30.94	112.32	26.30	0.92	0.37
Green	116.15	21.05	103.53	23.50	1.13	0.28
Blue	93.14	24.96	90.32	32.26	0.20	0.85
Spatial frequency						
Amplitude	2.79×10^9	0.77×10^9	2.19×10^9	0.73×10^9	1.62	0.13
HighW	1.06×10^5	0.29×10^5	0.85×10^5	0.26×10^5	1.52	0.15
HighH	1.06×10^5	0.30×10^5	0.87×10^5	0.26×10^5	1.36	0.19
LowW	1.17×10^5	0.30×10^5	0.95×10^5	0.25×10^5	1.63	0.13
LowH	1.20×10^5	0.31×10^5	0.95×10^5	0.27×10^5	1.70	0.11
Intensity gradient orientation and magnitude						
Magnitude	7.76	2.49	6.01	2.30	1.46	0.17
Orientation skewness	1.83	0.49	1.64	0.95	0.51	0.62
Orientation kurtosis	6.08	1.68	5.62	2.95	0.38	0.71

Note: M = mean, SD = standard deviation; subscripts: N = naturalistic, S = surrealistic. *t*-scores of *t*-test (df = 14).

2.3 Procedure

A block design was used with eight blocks per condition, each block comprising three pictures, ie 24 stimuli events per condition occurred. The order of stimuli and blocks was pseudo-randomised, and each picture was presented three times with different stimuli constellations per block (Presentation, Neurobehavioral Systems, USA). All pictures were framed with a black background. Subjects viewed the paintings via a mirror attached to the head-coil on an LCD screen behind the scanner. Stimuli were presented for 3500 ms, followed by a 1000 ms display of a black screen while subjects had to decide whether they were affected by the painting or not by pressing a button (LUMItouch, Photon Control, Canada). Subsequent to each block a fixation asterisk appeared on screen for 6000 ms. The subjective evaluations requested should refer to any kind of feelings about the painting ("Are you touched by the painting?").

Prior to the scanning session, detailed instructions were given and a training sequence was performed by each participant in order to guard against misunderstandings about the task.

The study was conducted with a 3T system (Philips ACHIEVA, Germany) at the University Hospital LMU Munich. For anatomical reference T1-weighted MPRAGE sequence was performed (TR = 7400 ms, TE = 3433 ms, FA = 8°, 301 sagittal slices, FOV = 240 mm × 256 mm, matrix = 227 × 227, inter-slice gap = 0.6 mm). For BOLD imaging T2*-weighted EPI sequence was used (TR = 3000 ms, TE = 35 ms, FA = 80°, 36 axial slices, slice thickness = 3.5 mm, inter-slice gap = 0 mm, ascending acquisition, FOV = 230 × 230 mm, matrix = 76 × 77, in-plane resolution = 3 × 3 mm). In total 168 functional volumes were acquired.

2.4 *Data processing and analysis*

Statistical analysis was done with MATLAB (MathWorks) and SPSS Statistics 19.0 (SPSS, USA). To analyze behavioural data, a MANOVA was computed with response type and reaction time as dependent variables. Correction for multiple comparisons was implemented by the Bonferroni procedure.

fMRI data were analysed with BrainVoyager 2.0.8 (BrainInnovations BV, The Netherlands). The first five functional volumes were discarded to avoid variable effects of blood-oxygen saturation on T1 relaxation due to instabilities of the magnetic field. All functional images were 3D motion-corrected (six-parameter rigid-body trilinear interpolation) and temporally high-pass filtered with a cutoff of two cycles in time course (removal of low frequency drifts). Functional data were subsequently aligned to the structural images, normalised (through the use of a piecewise linear transformation model) into Talairach stereotactic space to allow averaging across subjects by defining the eight landmark points of the reference system (Talairach and Tournoux 1988), resampled to 3 mm × 3 mm × 3 mm voxels and spatially smoothed to minimise noise and residual intersubject differences in anatomy (FWHM = 8 mm). Random effect general linear model was computed. Boxcar predictors were convolved with a two-gamma haemodynamic response function, and the BOLD-signal time course was normalised by z-transformation. Three contrasts were estimated—one to compare the two painting conditions and two for each painting condition against the control condition. Statistical maps for the specific contrasts were calculated as t-statistics on a voxel-wise basis and were corrected for multiple comparisons by false discovery rate q(FDR) < 0.005. Anatomical description was done referring to the AAL (Tzourio-Mazoyer et al 2002) atlas and probability maps of the visual cortex (Amunts et al 2007) adapted for BrainVoyager.

Furthermore, bivariate correlations between behavioural and neurometabolic data were computed to control for potential concomitant effects on the different activation levels in processing naturalistic and surrealistic paintings (regions of interest analysis).

3 Results

3.1 *Behavioural results*

There were no significant differences in the affective evaluation of naturalistic or surrealistic paintings according to the behavioural data. On average, subjects indicated to be affected almost equally by naturalistic ($M = 0.53 \pm 0.17$) and surrealistic ($M = 0.48 \pm 0.23$) paintings and lower by control stimuli ($M = 0.28 \pm 0.28$). An overall significant difference in response type ($F = 8.77$; $p < 0.01$; $\eta^2 = 0.20$) was driven by the difference between both painting conditions and the control condition ($p_{\text{natural–control}} < 0.01$; $p_{\text{surreal–control}} < 0.01$). There was also a significant difference in reaction time ($F = 8.64$; $p < 0.01$; $\eta^2 = 0.20$), with reactions on naturalistic paintings ($M = 5235 \pm 392$) being of longer duration than those on surrealistic paintings ($M = 4965 \pm 52$; $p = 0.03$) and on colour fields ($M = 4730 \pm 312$; $p < 0.01$).

3.2 *Neural correlates*

A subtraction analysis comparing the naturalistic and surrealistic condition was conducted to determine potential differences in the BOLD signal levels during processing of naturalistic versus surrealistic paintings. There was a significantly higher activation in the precuneus (Brodmann area/BA 7) and medial occipital cortex (BA 17, 18, 19) with similar extent in both hemispheres and in the right-middle temporal gyrus for naturalistic pictures (figure 1 and table 2). A higher activation in these areas during the naturalistic condition could also be found in contrast to the control condition (see supplemental material, figure S1a). Even though compared to the control condition similar activation patterns showed up in both painting conditions, only the surrealistic condition contrasted to the control condition additionally resulted in a deactivation in the precuneus and parts of the medial occipital and temporal cortex (see supplemental material, figure S1 and table S1).
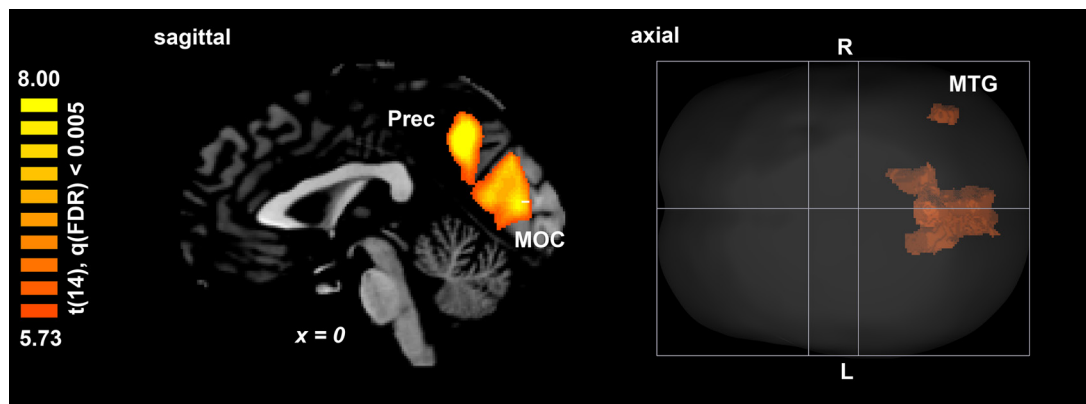
Figure 1. [In colour online, see http://dx.doi.org/10.1068/p7191] Neurometabolic level of processing for naturalistic versus surrealistic images. Sagittal section and axial glass brain view. Note: Prec = precuneus, MOC = medial occipital cortex, MTG = middle temporal gyrus, R = right, L = left.

Table 2. Brain regions with higher activation to naturalistic than surrealistic images.

Brain region	BA	Coordinates			t	Size in voxels
		x	y	z		
R precuneus	7	1	−55	40	10.49	58
R medial occipital cortex						
V1	17	12	−52	7	9.39	81
V2	18; 19	12	−49	4	9.03	54
R middle temporal gyrus	22; 39	45	−64	13	7.40	27
L precuneus	7	0	−55	40	11.32	72
L medial occipital cortex						
V1	17	−15	−52	4	10.67	182
V2	18; 19	−15	−52	2	10.04	91

Notes: Spatial cluster extension threshold $\geqslant 10$ voxels. Right (R) or left (L) hemisphere.
BA = Brodmann areas. The x, y, and z peak coordinates are in the Talairach stereotactic space.
t-scores of t-test (df = 14) significant by p (corrected for multiple comparisons) < 0.01.
Voxel size = 3 mm × 3 mm × 3 mm.

Out of the contrast between naturalistic and surrealistic paintings we anatomically defined two clusters of interest: precuneus and medial occipital cortex (together, 95% of the active clusters). Neither with subjective evaluation of the stimuli nor with reaction time were there any significant correlations for individual mean beta values ($p > 0.05$).

4 Discussion

Although subjects in this study did not show significant differences in their appraisal of emotional engagement in naturalistic and surrealistic images, there was a clear difference in the BOLD signal levels between the two presented image categories. When observing naturalistic paintings compared to surrealistic ones, subjects displayed a higher activity in striate and extrastriate areas of the visual system as well as in the precuneus. These differences in activation did not correlate with the behavioural measures.

Although we aimed to reduce concomitant factors as much as possible (see section 2), they, in principle, cannot be ruled out completely. We want to submit, however, our strong belief that the surrealistic and naturalistic paintings used in this study differ predominantly in content, not in formal criteria; this would, of course, have been different for other artistic movements like Impressionism, where paintings usually show different optical characteristics.

As all visual information has to pass the visual projection areas, the higher activity in the visual areas with the processing of naturalistic images compared to surrealistic images may indicate a feedback projection (top–down) from other central areas modulating activity on these input levels. Re-entrant projections from parietal to visual cortex could be observed (Goebel et al 2004; Koivisto and Silvanto 2012), specifically from the precuneus to the calcarine fissure (Keil et al 2009). These back-projecting modulating areas may be sensitive for the semantic content of the stimuli processed. However, it is difficult to distinguish between activations that result from recognition and those that are associated with a semantic classification and are therefore post-recognitional. A recent study has revealed that precuneus activity relates more to categorisation than to visual recognition (Schendan and Stern 2008). Thus, the higher activation in striate and extrastriate areas may be indicative of stronger feedback signals between areas of higher and lower cognitive functions, which are characteristic for top–down processing (Schmidt et al 2011). As search for meaning in paintings refers to content rather than painting style (Winston and Cupchik 1992), and as surrealistic visual information is questioning viewing habits (Proulx et al, 2010), top–down processing of surrealistic paintings may lead to a mismatch of perceived and expected representations of the visual world. The result, thus, also implies that the striate and extrastriate areas play a crucial role in a "reality check" of visual information.

The activity in the visual cortex as reported here is predominantly observed in areas corresponding to the periphery of the visual field. This is in accordance with observations of an inhomogeneity of the visual field, which is reflected, for instance, in different attentional networks corresponding to the central and peripheral area of the visual field (Bao and Pöppel 2007; Zhou et al 2010; Bao et al 2011). Thus, it can be concluded that looking at naturalistic pictures may elicit a higher attentional processing of peripheral stimuli, supporting our hypothesis that naturalistic pictures create a stronger embedding in a true-to-life context, which is not limited to the perifoveal region of just a few degrees of visual angle.

As a part of the cortical midline structures, precuneus activity has been suspected to be associated with visuo-spatial imagery, episodic memory retrieval, and even of what has been referred to as the "self" (Cavanna and Trimble 2006). Episodic memory retrieval is very likely to be associated with top–down processing (Sestieri et al 2010). However, surrealist paintings are not only unfamiliar but also disturb our sense of consistency and coherence and may therefore also hardly be related to our sense of the self. The higher activation of

the precuneus in the naturalistic condition supports the hypothesis that percepts matching expectations and therefore confirming specific aspects of reality can be linked both to prior experiences and innate programmes of the representation of the visual world (Spelke 1994). The results described here furthermore support the assumption that anticipatory perception provides the formation and maintenance of conceptual stability and perceptual identity (Pöppel 2010). The artists of the presented paintings and the subjects participating in this study all share Western cultural backgrounds. As mental representations of the world influence the perception of visual information, a cultural framing effect can be assumed that is implemented on the neural level and determines implicit information processing of visual stimuli in particular and sensory stimuli in general. Thus, self-reference in the processing of visual artworks can be assumed to be associated with culture-sensitive information (Han and Northoff 2008).

Taken together, the results of this study indicate that neural processing of visual artworks corresponds to what we consider as reality. Even though a painting never shows reality as such, the visual system differentiates between paintings that correspond to reality and that are in principle possible and those that violate physical laws and psychological expectations.

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