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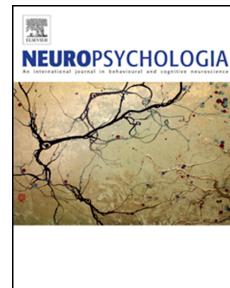
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Beauty in mind: Aesthetic appreciation correlates with perceptual facilitation and attentional amplification

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Beauty in mind: aesthetic appreciation correlates with perceptual facilitation and attentional amplification

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1 ABSTRACT

2 Neuroaesthetic research suggests that aesthetic appreciation results from the interaction
3 between the object perceptual features and the perceiver's sensory processing dynamics. In
4 the present study, we investigated the relationship between aesthetic appreciation and
5 attentional modulation at a behavioral and psychophysiological level.

6 In a first experiment, fifty-eight healthy participants performed a visual search task with
7 abstract stimuli containing more or less natural spatial frequencies and subsequently were
8 asked to give an aesthetic evaluation of the images. The results evidenced that response times
9 were faster for more appreciated stimuli.

10 In a second experiment, we recorded visual evoked potentials (VEPs) during exposure to the
11 same stimuli. The results showed, only for more appreciated images, an enhancement in C1
12 and N1, P3 and N4 VEP components. Moreover, we found increased attention-related
13 occipital alpha desynchronization for more appreciated images.

14 We interpret these data as indicative of the existence of a correlation between aesthetic
15 appreciation and perceptual processing enhancement, both at a behavioral and at a
16 neurophysiological level.

17

18 **Keywords:** neuroaesthetics; attention; EEG; aesthetic appreciation

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1 **1 Introduction**

2 Results from empirical aesthetics and neuroimaging studies suggest that aesthetic appreciation
3 emerges from the interaction between the object perceptual features and the perceiver's
4 perceptual processing dynamics (see Consoli, 2015 for a review). Ramachandran & Hirstein
5 (1999) proposed that visual aesthetic experiences are produced by stimuli which "optimally
6 titillate the visual areas of the brain" (page 1). Indeed, the perception of beauty is often
7 described as a mental state in which attention is focused on the stimulus perceptual features
8 (Apter, 1984; Chatterjee, 2011; Chatterjee and Vartanian, 2016; Cupchik and Winston, 1990;
9 Marković, 2012; Ramachandran and Hirstein, 1999; Shusterman, 1997). Consistently with
10 this idea, recent fMRI studies (Calvo-Merino et al., 2008; Cupchik et al., 2009; Jacobsen et al.,
11 2006; Koelsch et al., 2006; Munar et al., 2009; Vartanian and Goel, 2004) found enhanced
12 sensory processing during aesthetic appreciation. As it has been proposed, these results are
13 most likely induced by increased attentional engagement (Kirsch et al., 2016; Leder and
14 Nadal, 2014; Nadal, 2013). Such attentional modulation might also explain the perceptual
15 facilitation observed for more appreciated stimuli, as measured by enhanced behavioral
16 performance (Mather et al., 2016; Spehar et al., 2015), and the subjective feeling of
17 perceptual fluency (Carbon and Albrecht, 2016; Forster et al., 2015; Reber et al., 2004, 1998;
18 Reber and Schwarz, 2001; Singhal et al., 2007). However, to the best of our knowledge, there
19 is no electrophysiological evidence of a direct link between aesthetic appreciation and an
20 increased attentional engagement, which is the object of investigation of the present study.
21 EEG signals can efficacely capture the attentional dynamics following the presentation of a
22 stimulus: event-related responses provide well validated objective indexes of attentional
23 engagement both in the time domain (Mangun and Hillyard, 1991; Zani and Proverbio, 2012)
24 - by measuring the voltage of the evoked response- and in the time-frequency domain
25 (Klimesch, 2012; Mishra et al., 2012; Peng et al., 2012), by measuring the spectral power of

1 the evoked responses. More specifically, C1 and N1 components of the VEP and alpha event-
2 related desynchronization (ERD) have long been known to be modulated by attention to the
3 stimulus (Klimesch, 2012; Mangun and Hillyard, 1991; Warbrick et al., 2014; Zani and
4 Proverbio, 2012).

5 Here we wanted to investigate the modulation of attention during aesthetic appreciation of
6 content-free computer-generated abstract visual stimuli, containing different spatial
7 frequencies. A number of studies show that humans tend to perceive images with spatial
8 frequencies following the power law $1/f^B$, with B values approaching 2, as aesthetically more
9 pleasing (Menzel et al., 2015; Spehar et al., 2015). Interestingly, such preferred power
10 spectrum patterns are common both in natural environments and in visual arts (Johnson and
11 Baker, 2004; Redies et al., 2008). The power spectrum slope B was also found to influence
12 sensory processing efficiency: the ability of subjects to discriminate among visual stimuli
13 peaks when the images are made more ‘natural’ by manipulating the slope (B) of the spatial
14 frequencies power spectrum (Párraga et al., 2000). Altogether these findings make the power
15 spectrum slope a well-suited variable to investigate processing enhancement related to
16 aesthetic appreciation.

17 In a first experiment, we investigated at a behavioral level the relationship between perceptual
18 facilitation and aesthetic appreciation, as a function of image spatial frequency: we recorded
19 response times while subjects performed a visual search task of a grey dot embedded in more
20 or less appreciated abstract images with different power spectrum slopes (§ 2.1.2 *Stimuli*). In
21 a second experiment, to assess the relationship between attentional engagement and aesthetic
22 appreciation, we recorded the VEPs in response to the same more or less appreciated
23 background images.

24 We expected to observe, only for more appreciated images: 1) behavioural perceptual
25 facilitation (i.e., reduced response times) in the visual search task; 2) enhanced EEG

1 attentional indexes, such as increased amplitude of C1 and N1 components (Mangun &
2 Hillyard, 1991; Zani & Proverbio, 2012) and more pronounced alpha desynchronization over
3 occipital areas (Klimesch, 2012; Peng et al., 2012; Pfurtscheller et al., 1994; Sigala et al.,
4 2014).

5

6

7 **2 Materials and methods**

8

9 **2.1 Experiment 1**

10

11 **2.1.1 Participants**

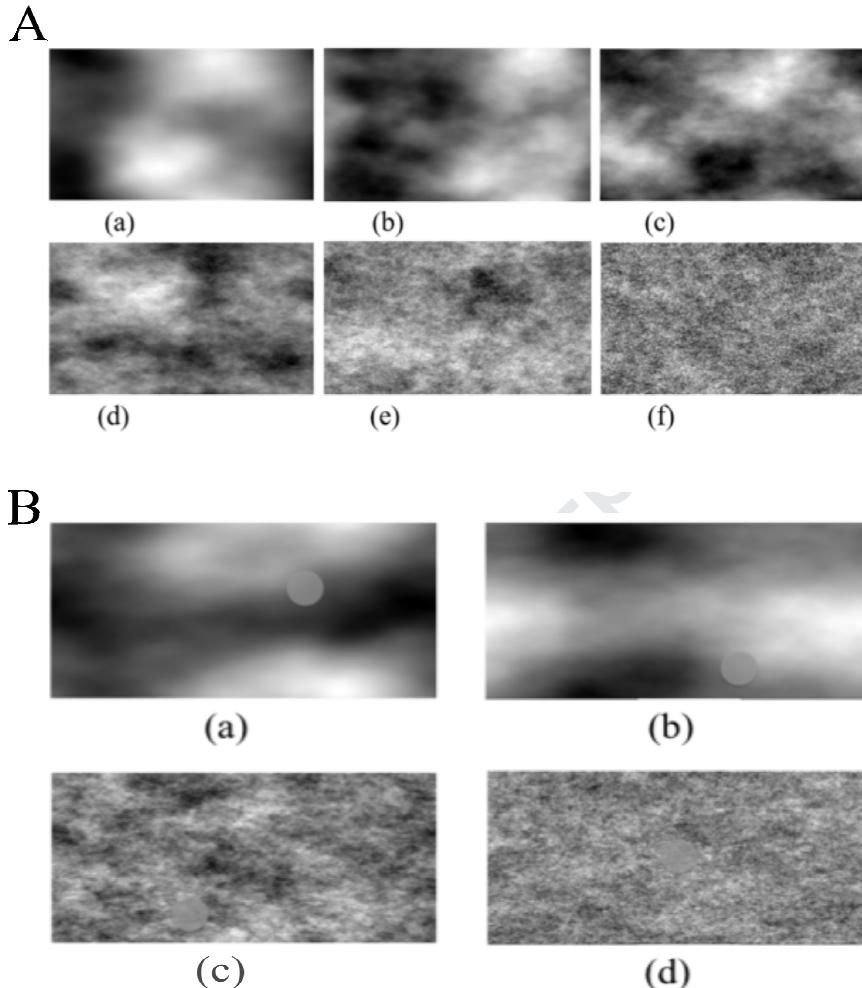
12 Fifty eight right handed healthy subjects (females: 30; age: 23.8 ± 2.5 ; education: 15 ± 2)
13 participated in the study. All participants had normal or corrected to normal vision. All
14 participants gave their written informed consent to participate to the study, which conformed
15 to the standards required by the Declaration of Helsinki and was approved by the local ethics
16 committee (University of Turin).

17

18 **2.1.2 Stimuli**

19 We employed 2D black and white noise-images randomly created with the IDL software
20 (Harris Geospatial Inc. USA). All images were generated according to the power law $1/f$, so
21 that the images spectral power (P) of spatial frequencies (f) is defined by a power law
22 $P(f)=1/f^B$. The software allowed to specify the exponent B value (i.e., the power spectrum
23 slope). We generated 21 different categories of stimuli with 21 different B values ranging
24 from 0.8 to 2.8 in steps of 0.1. We knew from previous studies that aesthetic appreciation
25 peaks for images with a power spectrum defined by a $1/f^B$ power law with B values

1 approaching 2 (Spheer et al. 2015). Therefore, we centred the distribution of B values around
 2 $B=1.8$. In *Figure 1 (panel A)* we show six examples of representative stimuli from the initial
 3 image set.



4
 5 **Fig.1. Experimental stimuli.** Images a)-f) in **Panel A** are extracted from the initial set of 105 images (21 categories): each
 6 image is a representative example of a stimulus category with a different B exponent value: **(a)** $B=2.8$, **(b)** $B=2.4$, **(c)** $B=2$, **(d)**
 7 $B=1.6$, **(e)** $B=1.2$, **(f)** $B=0.8$.

8 **Panel B** depicts images employed in the visual search task. The target (grey circular dot) is here superimposed on 4
 9 backgrounds pertaining to 4 representative image categories (out of the total 21 categories) characterized by $B =2.8$ **(a)**, 2.3
 10 **(b)**, 1.3 **(c)**, 0.8 **(d)**. In order to render the grey target more visible to the reader, images in Panel B have been magnified
 11 relative to images in Panel A.

12
 13 Five different images for each of the 21 B categories were generated, for a total of 105 images.
 14 During the collection of aesthetic judgments (*§2.1.4 Experimental procedures*), all 105

1 images (from now on *Backgrounds*) were shown once, whereas during the visual search task
2 the same *Backgrounds* were shown twice, once with a superimposed 1 cm wide, semi-
3 transparent, grey dot (from now on *Target*), and once without. The use of target-free images
4 served to prevent habituation and participants' distraction during the task. To lower the
5 probability of the occurrence of anticipatory responses, the *Target* could appear in five
6 different positions: centrally (aligned with the subject midsagittal plane) and in four
7 peripheral positions located at 10 degrees of visual angle from the geometrical image center
8 along the horizontal and vertical meridians (see *Figure 1, panel B*). The total *Background* set
9 employed in the visual search task consisted of 210 images, 10 for each *B* category (5 with
10 and 5 without the target).

11

12 **2.1.3 Apparatus**

13 The set up was identical in *Phase 1* and in *Phase 2* (§ 2.1.4 *Experimental procedures*).
14 Participants sat comfortably at a table in a fixed position, distant 60 cm from a 53 cm (21
15 inches) computer screen, with the screen center aligned with the subject's trunk vertical
16 midline. The left arm was resting on the corresponding leg, while the right arm was placed on
17 the desk. Subjects had their right index finger resting on the "A" keyboard button and the
18 middle finger on the adjacent "S" button. They were asked to press "A" as fast as possible
19 when the target was present, and "S" when the target was absent. The subjects' right hand and
20 the response keys were aligned with the trunk vertical midline.

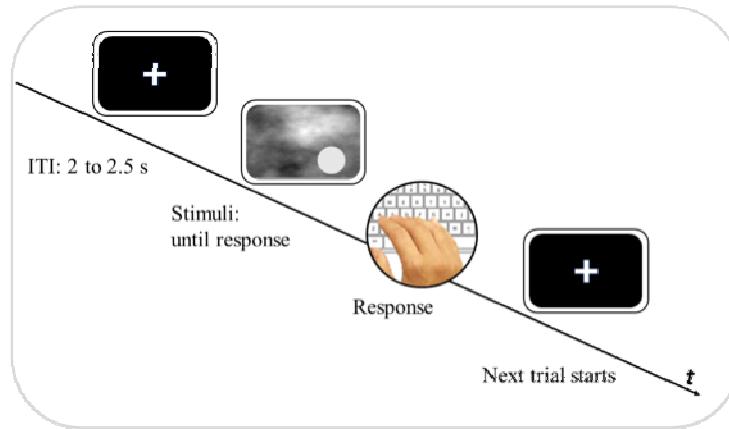
21

22 **2.1.4 Experimental procedures**

23 *Phase 1 – Visual search task*

24 Stimuli were presented in a random order with an inter-trial interval ranging between 2 and
25 2.5 s. Subjects were instructed to stay still and look at a 1x1cm wide white fixation cross
26 placed in the center of the computer screen and aligned with the subjects' trunk vertical

1 midline. The fixation cross was present on the screen for the whole duration of the inter-trial
 2 interval. *Targets* and *Backgrounds* appeared at the same time and remained visible until
 3 response (*Figure 2*). Response time and accuracy data were collected.



4
 5 **Fig.2. Timeline of Experiment 1.** Participant fixated on a central cross for the ITI duration. Backgrounds appeared at the
 6 center of the screen and remained until response. Participants were asked to indicate whether the target was present or not by
 7 pressing two adjacent buttons on the keyboard in front of them. As soon as they responded the fixation cross was back on the
 8 screen.

9

10 *Phase 2 -Aesthetic judgments (AJs) collection*

11 Following the visual search task, after a 5 minutes rest, participants evaluated the beauty of
 12 the 105 *Background* stimuli employed in *Phase 1*. Participants were asked to look at a 1x1cm
 13 wide white fixation cross placed in the center of the computer screen, against a black
 14 background, and then to pay attention to the images appearing on screen (stimulus duration 1
 15 s). The *Backgrounds* were presented in a random order. Participants were asked to report their
 16 aesthetic appreciation judgment on a *Likert* scale ranging from 0 ('I completely dislike it') to
 17 9 ('I like it very much') by pressing the corresponding numerical key on the computer
 18 keyboard. Judgments were automatically recorded for each trial. Following the response, the
 19 fixation cross appeared back on the screen. Inter-trial intervals ranged between 3 and 5 s.
 20 Both experimental procedures were programmed and administered using E-Prime 2.0
 21 software (Psychology Software Tools, Inc. USA).

1
2 **2.1.5 Data analysis**
3 Incorrect trials were excluded from the analysis. For each participant, we computed the mean
4 RT for each category. Every subject evaluated 5 different images for each *Background*
5 category and mean judgments were averaged across subjects to obtain one value for each of
6 the 21 *Background* categories. A standard two-tailed Pearson correlation analysis was then
7 performed on all-subjects mean RTs and AJs from the 21 *Background* categories.
8

9 **2.2 Experiment 2**
10

11 **2.2.1 Participants**

12 Thirteen healthy right-handed subjects (females: 7; age: 25 ± 1.8 ; education: 16 ± 2.3)
13 participated in the study. All subjects had normal or corrected to normal vision and gave their
14 informed consent to participate to the study, which conformed to the standards required by the
15 Declaration of Helsinki and was approved by the local ethics committee (University of
16 Torino).

17 To determine the sample size for the EEG experiment we collected the EEG recordings of 5
18 participants who participated in a pilot experiment identical to *Experiment 2*. We then
19 extracted average C1 peak amplitudes (*§3.2 Results*), corresponding to each of the 5
20 *Background* categories (*§2.2.2 Stimuli*), from single subject recordings (electrode O_z).

21 “*Background category*” was considered as a within-subjects factor in a repeated measure
22 ANOVA. The effect size and significance value for the effect of the factor “*Background*
23 Category” ($\eta^2_{\text{p.}}=0.239$; $p=0.327$; $\rho=0.326$) was subsequently used in a power analysis to
24 determine the sample size (N=13) required for a statistical power level set at 0.8 and an alpha
25 significance level set at 0,05 (critical F=1.19; actual power=0.80004).

1

2 **2.2.2 Stimuli**

3 Stimuli were drawn from the *Background* set of images employed in *Phase 2 of Experiment 1*
4 (*§ 2.1.2 Stimuli* and *§ 2.1.3 Apparatus*). The selected *Backgrounds* belonged to 5 different
5 categories defined by the following *B* exponent values: 0.8, 1.3, 1.8, 2.3 and 2.8. Twenty
6 images were shown for each *B* category, for a total of 100 images presented in two
7 experimental blocks (50 images per block). None of the subjects had ever seen the
8 experimental images before or was informed about their characteristics. From the results of
9 *Experiment 1* (*§3.1* and *Figure 3*) and previous studies (Spehar et al., 2015) with large
10 samples, we expected that images with extreme *B* values (*B* = 0.8 and 2.8) were on average
11 less appreciated than images with intermediate *B* values (*B* = 1.3 and 2.3), while images with
12 *B*=1.8 were the most appreciated ones. Including *Backgrounds* with steeper or smoother *B*
13 slopes than highly appreciated *Bs*' allowed us to discriminate between ERP modulations
14 eventually induced by high/low spatial frequencies and those correlated to aesthetic
15 judgements.

16

17 **2.2.3 Experimental procedure**

18 The set-up was identical to that of *Experiment 1*, except that *Targets* were absent and subjects
19 were only asked to look at the *Backgrounds* presented on the screen while EEG data were
20 recorded. *Backgrounds* were presented in a random order (stimulus duration 500 ms),
21 preceded and followed by a white fixation cross (4 to 5 s inter-stimulus interval). The
22 experiment was divided into two identical blocks, composed of 50 images each. In between
23 the two experimental blocks participants were allowed to rest for about 5 minutes. Each block
24 lasted approximately 6 minutes. To ensure that subjects were attentively performing the task,
25 twenty catch trials were included in a random order within the experimental sequence (20% of
26 the total number of trials), consisting of a semi-transparent red dot superimposed onto the

1 same *Backgrounds* employed in valid trials. Subjects had to verbally report the presence of
2 catch trials to the experimenter. Catch trials were successively excluded from statistical
3 analyses. Subjects failing to report more than 2 catch trials were excluded from the analyses.
4 After the EEG session participants performed a brief aesthetic evaluation task identical to the
5 one described in *Experiment 1* (§2.1.4) with the only exception that they evaluated only
6 *Backgrounds* belonging to the 5 categories selected in *Experiment 2*. In the aesthetic
7 evaluation task, subjects evaluated 5 images for each Background category for a total of 25
8 stimuli.

9

10 **2.2.4 Electrophysiological recordings and data analysis**

11 EEG activity was recorded using 32 Ag-AgCl electrodes placed on the scalp of the participant
12 according to the International 10-20 system and referenced to the nose. Electrode impedances
13 were kept below 5 kΩ. The electro-oculogram (EOG) was recorded from two surface
14 electrodes, one placed over the right lower eyelid and the other placed lateral to the outer
15 canthus of the right eye. Signals were recorded and digitized by using a *HandyEGG*
16 (Micromed, Treviso – IT) amplifier with a sampling rate of 1024 Hz.

17 EEG data were pre-processed and analyzed with Letswave6 toolbox (Nocions, Ucl. BE) for
18 Matlab (Mathworks, Inc. USA). Continuous EEG data were divided into epochs of 1.5 s (total
19 duration), including 500 ms pre-stimulus and 1 s post-stimulus intervals. Epochs were band-
20 pass filtered (1-30 Hz) using a fast Fourier transform filter and baseline corrected using the
21 interval from -0.5 to 0 s as reference. Artifacts due to eye movements were subtracted using
22 Independent Component Analysis (ICA – Jung et al., 2000). Epochs belonging to the same
23 *Background* category (i.e. same *B* exponent category) were then averaged, to obtain five
24 average waveforms (i.e. *B* equal to 0.8, 1.3, 1.8, 2.3 and 2.8) for each subject. Single subjects
25 preprocessed epoched data are available at: Sarasso, P. (2017), “The flow of beauty”,
26 Mendeley Data, v1 <http://dx.doi.org/10.17632/rrsxt86p4x.1>

1 *Statistical analyses in the time domain.* To test for significant differences among the ERPs
2 elicited by different image categories, we performed a one-way, repeated measures, point-by-
3 point ANOVA, with a three levels Factor corresponding to beauty rankings according to the
4 results of *Experiment 1* (§3.1) and *Experiment 2* (§3.2). Single subjects' average waveforms
5 corresponding to less appreciated images with $B=0.8$ and 2.8 were averaged together and
6 assigned to factor level 1; waveforms corresponding to images with $B=1.3$ and 2.3 were
7 averaged together and assigned to factor level 2 and waveforms corresponding to highly
8 appreciated images with $B=1.8$ were assigned to factor level 3. As a result, we obtained one
9 waveform per participant for each of the three factor levels, which constituted the input of the
10 point-by-point ANOVA (Ronga et al., 2013; Bruno et al., 2019). Correction for multiple
11 comparisons was applied via clustersize-based permutation testing (Maris & Oostenveld,
12 2007; 1000 permutations; alpha level=0.05; percentile of mean cluster sum=95). Clusters
13 were based on temporal contiguity and spatial adjacency of a minimum of two electrodes
14 (Novembre et al., 2018).

15 Furthermore, we computed the correlation between each time point from single subjects'
16 ERPs and mean AJs of the eliciting *Background* images from *Experiment 2* (§2.2). On each
17 time point, this analysis (Novembre et al., 2018) computed a *r*-value between the amplitudes
18 of the waveforms corresponding to the five different *Background* categories and their mean
19 AJs (AJs were averaged across the 13 participants). The outcome of the correlation analysis
20 was a 0.5 s long time series of correlation coefficients for each channel for each subject. This
21 constituted the input for a group-level two-tails point-by-point t-test with permutation-based
22 correction for multiple comparison (Maris & Oostenveld, 2007; 1000 permutations; alpha
23 level=0.05; percentile of mean cluster sum=95; minimum number of adjacent channels=2).
24 The test compared single subjects correlation coefficients against 0 at each time point. This
25 allowed us to verify whether the waveform components highlighted by the ANOVA results
26 were also significantly correlated to the AJs of the observed images and to evidence other

1 waveform components which could possibly correlate with AJs but failed to survive cluster
2 correction in the ANOVA.

3 *Statistical analyses in the time-frequency domain.* Time-frequency representations were
4 computed for each single pre-processed epoch using a Short-term Fast-Fourier transform
5 (STFFT) with a Hanning window width of 0.25 s. The STFFT expressed the amplitude as a
6 function of time (relative to stimulus onset) and frequency. The resulting estimates were
7 averaged across single trials belonging to the same *Background* category, to obtain one single
8 spectrogram for each of the five *Backgrounds* per participant. For each frequency, estimates
9 were displayed in these spectrograms as an event-related percentage (ER%) change in
10 oscillation amplitude relative to a baseline (-0.5 to -0.1 s pre-stimulus). ER% changes
11 constituted the input of subsequent analyses.

12 To test for the presence of significant modulations in ERD after the presentation of different
13 backgrounds the same approach implemented in the time domain was used in the time-
14 frequency domain (see above). Namely, we used pairwise point-by-point t-tests comparing
15 ER% changes (Valentini et al., 2014) following the presentation of different *Backgrounds*.
16 ER% elicited by the presentation of the five Background categories were compared against all
17 others for a total of ten t-tests. Correction for multiple comparisons was applied via
18 clustersize-based permutation testing (Maris & Oostenveld, 2007; 1000 permutations; alpha
19 level=0.05; percentile of mean cluster sum=95).

20 To help visualize ER% changes following different *Backgrounds* we extracted the minimum
21 ER% estimate for the alpha frequency band (7.5 to 12.5 Hz) within a time period lasting from
22 0.2 s to 0.6 s post-onset. Minimum ER% were then averaged across participants to obtain one
23 single average value for each *Background*. Moreover, single subjects baseline corrected ER%
24 were averaged across participants to obtain one single spectrogram for each *Background*.

25

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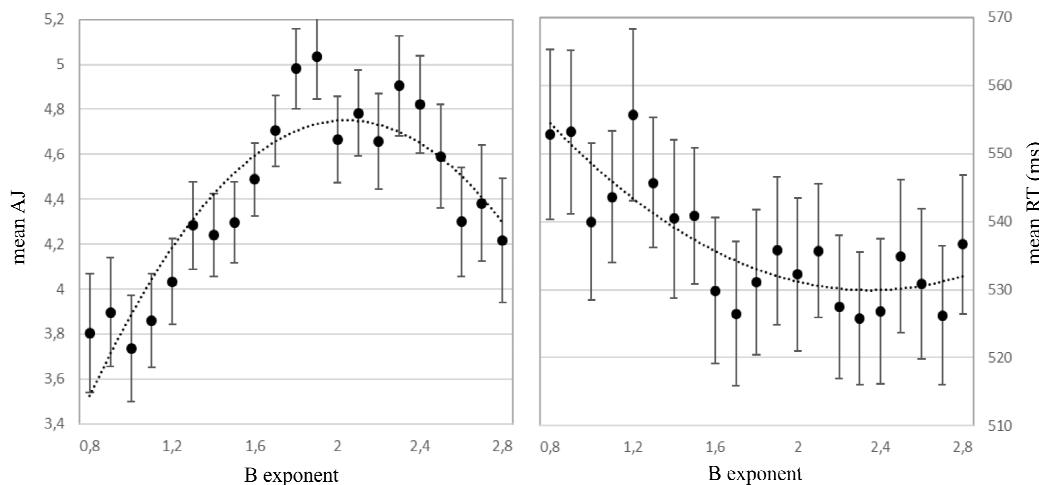
2 **3 Results**

3

4 **3.1 Experiment 1**

5 All participants correctly performed the task [mean number of incorrect trials/subject: 6,5 out
 6 of 210 (3.1%)]. The average participants' response time was 540 ms (SD=82 ms). Incorrect
 7 trials were equally distributed among image categories.

8 Mean judgment values across categories replicated the findings from previous literature,
 9 showing an inverted u-shape function with higher preferences for images with B values close
 10 to 2 (*Figure 3*). The mean RTs for all subjects are shown in *Figure 3* (right panel) and show an
 11 opposite trend relative to AJs. The negative relationship between all-subject average RTs and
 12 AJs is evidenced by the significant Pearson correlation coefficient ($r=-0.728$; 95% CI: -
 13 $1.057 < r < -0.4$; $p < 0.001$; $N=21$).



14

15 **Fig.3. Mean aesthetic ratings (left panel) and response times (right panel)** ($N=58$). Single subject RTs were normalized
 16 around the mean RT and then averaged across subjects ($N=58$; grand-average). Error bars represent standard errors. Dotted
 17 curves represent the best-fitted second order polynomial trend lines.

18

19 **3.2 Experiment 2**

1 The results of the aesthetic evaluation are depicted in *Figure 4 (panel A)* and replicate the
2 findings of previous studies and *Experiment 1. Backgrounds* with $B=1.8$ were rated as more
3 beautiful than *Backgrounds* with $B=1.3$ and $B=2.3$, while *Backgrounds* with $B=0.8$ and $B=2.8$
4 were the least preferred ones.

5 The point-by-point ANOVA analysis (*Figure 5*) revealed differences in two ERP time
6 intervals between waveforms from high-, medium- and low-appreciation ranked *Background*
7 categories: 1) the C1 early occipital-posterior component (Di Russo et al., 2002; Hillyard &
8 Anllo-Vento, 1998) peaked around 49 ms post-stimulus; 2) the N1 posterior-central
9 component (Johannes et al., 1995; Vogel & Luck, 2000) peaked around 122 ms post-stimulus
10 (slightly later at 142 ms for *Backgrounds* with $B=2.8$). In *Figure 5*, grand-average responses
11 for the five *Background* categories are presented, together with F-values and significant
12 clusters from occipital (Oz) and central (Cz) electrodes.

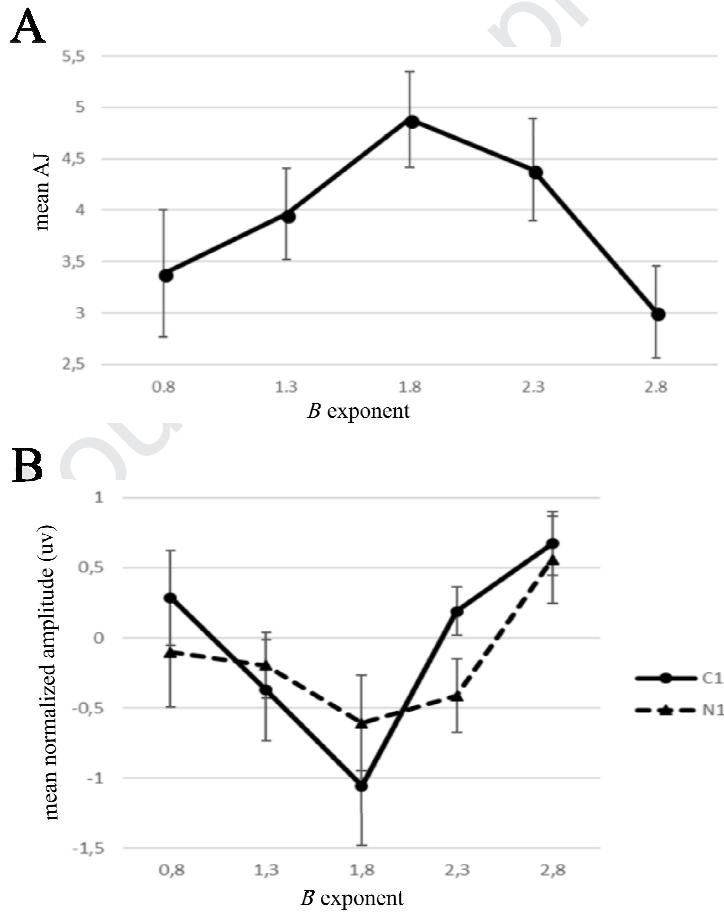
13 C1 and N1 amplitudes were also significantly correlated to mean AJs as evidenced by the
14 point-by-point correlation analysis (*Figure 6*). The cluster-corrected t-test performed on single
15 subjects' correlation coefficients highlighted a significant cluster ranging between 0.045 and
16 0.076 s post onset on the electrode O_z corresponding to C1 and another significant cluster
17 ranging between 0.107 and 0.135 s post onset on the electrode C_z corresponding to N1.

18 Moreover, the analysis indicated a significant correlation between mean AJs and later parieto-
19 occipital P3 and N4 components, as revealed by a significant cluster ranging between 0.269
20 and 0.293 s post onset on the electrode O_z (corresponding to P3). Correlations between AJs
21 and N4 amplitudes were indicated by a smaller significant cluster on O_z (range: 0.387-0.407 s)
22 and a larger cluster on C_z (range: 0.386-0.428 s). *Figure 4 (panel B)* plots the normalized
23 grand-average of C1 and N1 single-subject peaks.

24 The time-frequency analysis revealed the expected ERD in the alpha band that is usually
25 evident over occipital areas after the presentation of a visual stimulus (Klimesch, 2012; Sigala
26 et al., 2014). The latency and scalp distribution of alpha ERD closely matched those of

1 previous studies (Abeles and Gomez-Ramirez, 2014; Mishra et al., 2012; Peng et al., 2012).
 2 The analysis revealed an increase of alpha ERD after the presentation of more appreciated
 3 *Backgrounds* with $B=1.8$, as evident in the average spectrogram and in mean ER% from Oz
 4 displayed in *Figure 7*. Only the following pairwise t-tests revealed the presence of significant
 5 clusters: $B=0.8$ vs $B=1.8$; $B=1.3$ vs $B=1.8$; $B=1.8$ vs $B=2.3$; $B=1.8$ vs $B=2.8$; $B=2.3$ vs $B=2.8$.
 6 Significant clusters from point-by-point t-tests were mainly included in the alpha band in a
 7 time period comprised between 0.2 and 0.6 s post-onset. P values from significant clusters
 8 from Oz are displayed in *Figure 7*.

9

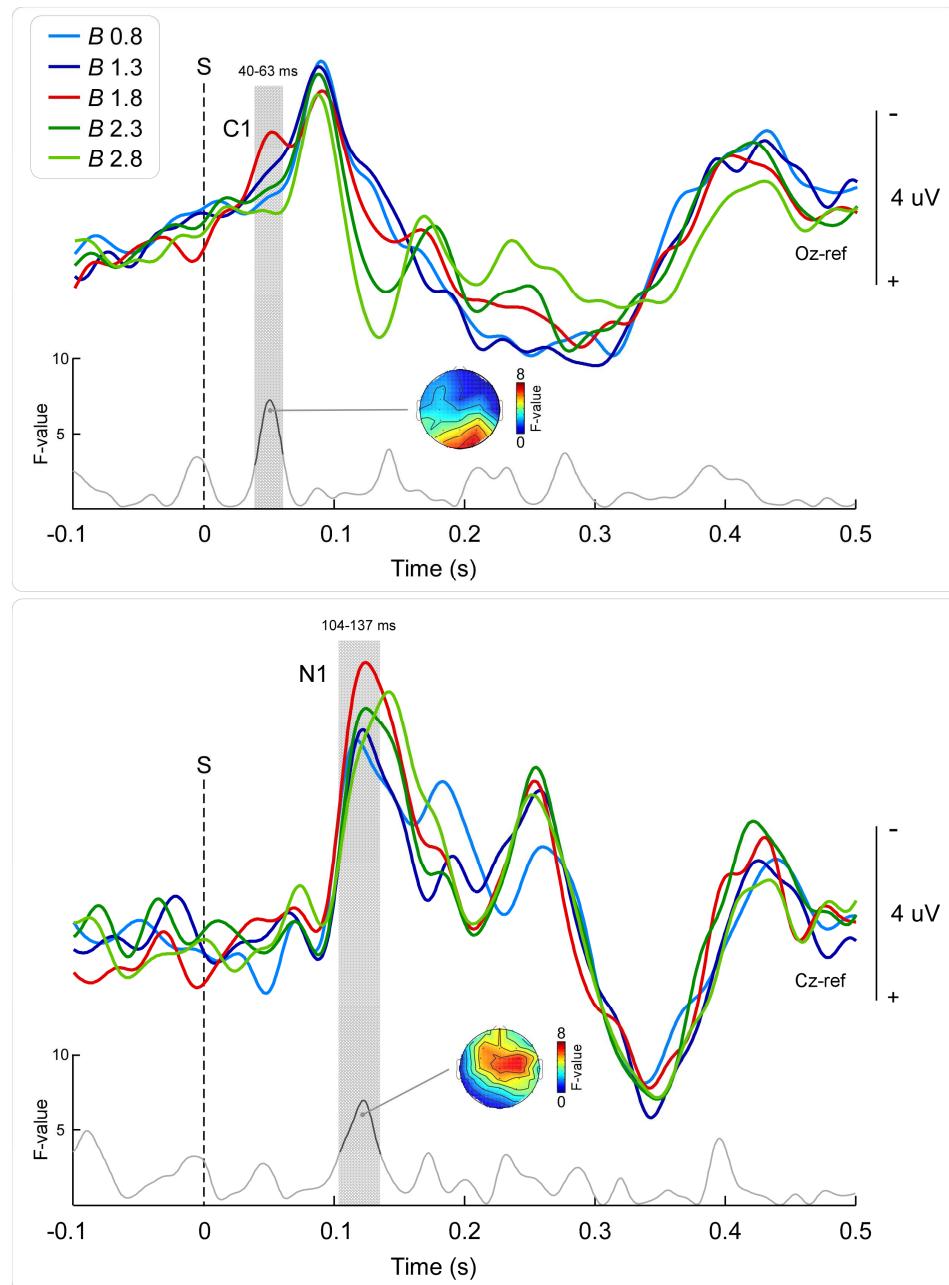


10

11 **Fig.4. Mean aesthetic ratings and mean N1 and C1 peaks (N=5).** **Panel A:** Single subjects' (N=13) AJs were averaged to
 12 obtain a mean value for each *Background* category. The graph in **Panel B** shows the grand-average of N1 (dashed line) and
 13 C1 (solid line) peaks. C1 and N1 Peaks were normalized around their mean to display them on a common scale. Error bars
 14 represent standard errors.

1

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3

4 **Fig.5. Point-by-point ANOVA:** waveforms represent grand-average ERPs for the 5 different image categories registered on
 5 Oz (top panel) and Cz (bottom panel). Each ERP represents the average of 20 trials per participant. Shaded areas represent
 6 the significant clusters evidenced by the cluster-based permutation analysis with 250 permutations. Maps depict the scalp
 7 distribution of F-values at 50 and 120 ms post-stimulus onsets. Point-by-point F-values for the two channels are displayed in
 8 the graph below each panel. The dotted line represents stimulus (S) onset.
 9

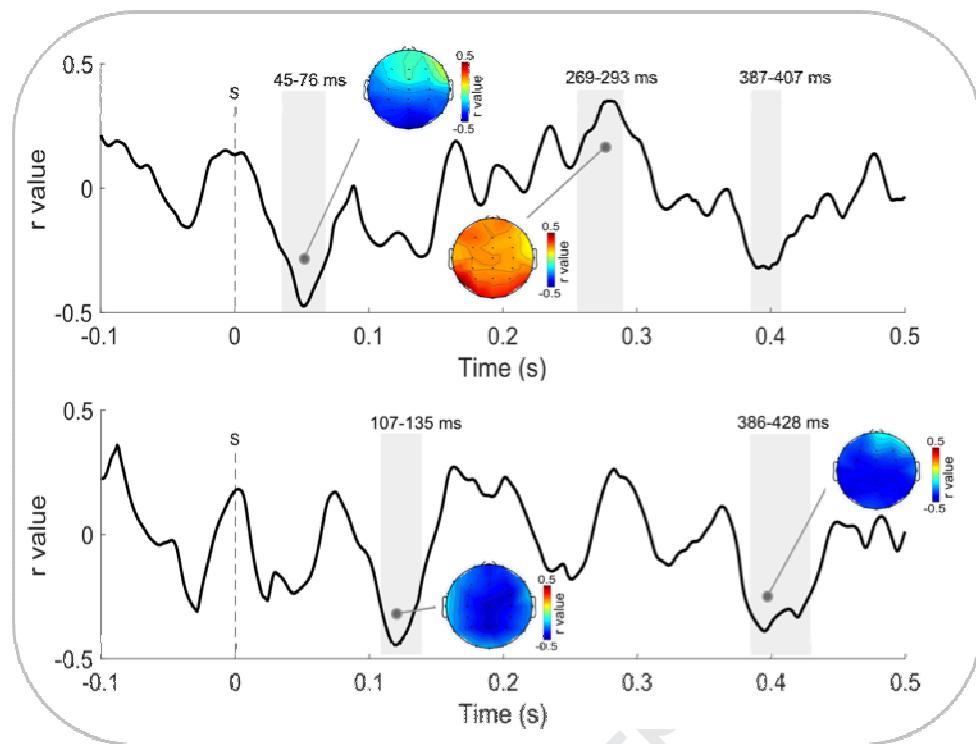
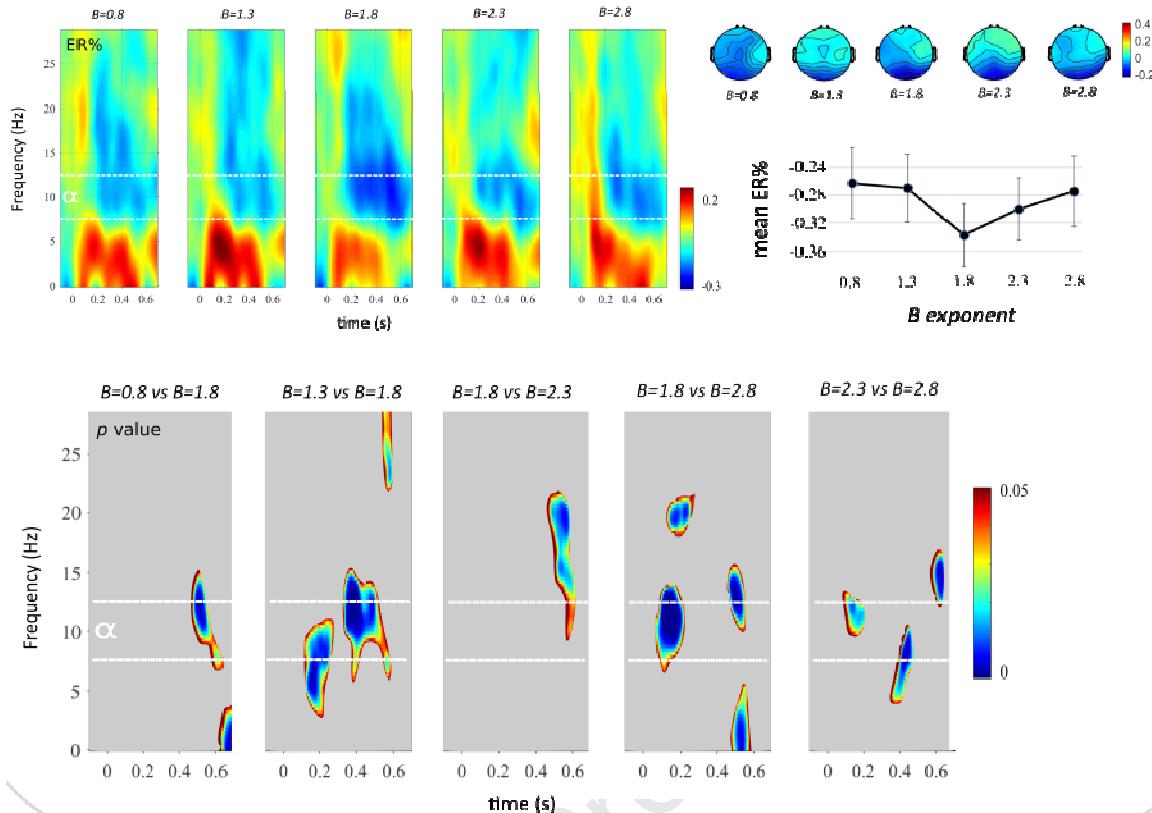


Fig.6. Correlation between C1, N1, P3 and N4 amplitudes and AJs. The graph shows all-subjects' mean correlation coefficients (r) between AJs and the amplitudes of waveforms registered on O_z (top panel) and C_z (bottom panel). Shaded areas represent significant clusters evidenced by the point-by-point t-test comparing single subjects' correlation coefficients against 0. Scalpmaps depict the distribution of mean correlation coefficients across channels at peak latencies (50ms post onset for C1; 120ms post onset for N1; 300ms post onset for P3; 400ms post onset for N4)



1 **Fig.7. Time-frequency analysis.** The graph shows the grand-average spectrogram and mean alpha (7.5 to 12.5 Hz) ER%
2 from Oz for each of the five Background categories (upper panel). Colors in the spectrograms represent ER% changes in
3 oscillation amplitude relative to the baseline. Scalpmaps represent the average minimum value of ER% registered in the
4 alpha band (7.5 to 12.5 Hz) between 0.2 and 0.6 s after stimulus onset. In the lower panel p values from single t-tests
5 (computed on channel Oz) are displayed as a function of time and frequency. Significant clusters are colored while grey areas
6 contain p values which did not survive cluster-based correction. Only t-tests which showed at least one significant cluster
7 were reported in the figure.
8

9

10 **4 Discussion**

11 The results of experiment 1 and 2 confirmed our hypothesis of the presence of a correlation
12 between aesthetic appreciation and attentional engagement: more appreciated abstract stimuli
13 were associated to perceptual facilitation (i.e., faster RTs) and EEG indexes of enhanced
14 attentional activation (i.e., larger C1 and N1 VEP components and increased alpha ERD).

15 *Behavioural perceptual facilitation related to aesthetic appreciation.* The results of
16 *Experiment 1* revealed the existence of a relationship between aesthetic appreciations and RTs
17 in a visual search task with content-free abstract stimuli. Aesthetic appreciation was found to

1 be inversely correlated to RTs: participants were faster in detecting targets embedded in more
2 appreciated stimuli. We propose that this effect might be caused by enhanced visual
3 sensitivity for preferred stimuli, defined by a power law with B values close to 2 (Spehar et al.,
4 2015). Such values characterize also images of natural environments, to which the human
5 visual system has adapted both phylogenetically and an ontogenetically (Graham and Field,
6 2010; Olshausen and Field, 1996). Interestingly, natural-like image statistics are also
7 consistently found in visual arts (Graham & Redies, 2010) and are related to aesthetic
8 appreciation (Spehar et al., 2015, 2003; Street et al., 2016). In sum, the results of *Experiment*
9 1 demonstrate the existence of a positive correlation between aesthetic appreciation and
10 behavioural indexes of attentional enhancement (Ronga et al., 2018; Sarasso et al., 2019).

11
12 *Electrophysiological indexes of attentional enhancement related to aesthetic appreciation.* In
13 *Experiment 2*, the analysis of VEPs revealed a significant correlation between C1, N1, P3 and
14 N4 amplitudes and AJs (*Figure 6*). C1 and N1 amplitudes, peaking around 50 ms and 120 ms
15 post stimulus onset, respectively, seem to be more strongly modulated by AJs than P3 and N4
16 amplitudes. The amplitude of attention-related C1 and N1 early components was indeed
17 significantly different between more and less appreciated stimuli, while P3 and N4 amplitudes
18 were not (*Figure 5*). Moreover, as we expected, more appreciated stimuli induced stronger
19 attention-related ERD in the alpha frequency over occipital areas between 200 and 600 ms
20 post stimulus onset (*Figure 7*).

21 Consistently with what mentioned above, C1 is considered to mainly capture neural activity
22 from V1 (Martínez et al., 1999; Noesselt et al., 2002), reflecting early attentional processing
23 (Kelly et al., 2008; Zani and Proverbio, 2012). Previous studies investigating exogenous
24 cueing of involuntary attention showed enhanced C1 amplitude for validly vs invalidly cued
25 targets (Dassanayake et al., 2016; Fu et al., 2010, 2009). Similarly, C1 responses are more
26 pronounced after the presentation of motivationally relevant stimuli, such as threat-related

1 images or images associated with monetary outcomes (Rossi et al., 2017; Stolarova et al.,
2 2006). N1 is also considered an index of early attentional processing (Mangun and Hillyard,
3 1991), presumably reflecting the gain control or selective amplification of sensory inputs
4 (Hillyard and Anllo-Vento, 1998). Crucially, posterior N1 was shown to index exogenous (i.e.,
5 bottom-up) object-based attentional up-weighting of sensory input (Marzecová et al., 2018 for
6 a review). Moreover, larger N1 amplitudes are usually correlated to more efficient processing
7 (Van den Berg et al., 2016; Vogel and Luck, 2000). Furthermore, Van den Berg and colleagues
8 (2016) showed that response times in a visual search task could be predicted by N1
9 amplitudes.

10 Alpha oscillation amplitude in occipital areas is generally found to be reduced (stronger alpha
11 ERD) in presence of increased attention (Bollimunta et al., 2008; Ergenoglu et al., 2004;
12 Klimesch, 2012; Mishra et al., 2012; Peng et al., 2012; Sigala et al., 2014) and perceptual
13 performance (Bays et al., 2015; Nenert et al., 2012). Attention and processing enhancements
14 are often associated with a post-stimulus decrease in alpha synchronization, since the latter is
15 thought to reflect the release of inhibition of cortical excitability (Cebolla et al., 2016;
16 Klimesch et al., 2007) thus regulating stimulus-related response in areas encoding sensory
17 inputs (Abeles & Gomez-Ramirez, 2014).

18

19 *What is the evolutionary meaning of the correlation between attentional enhancements and*
20 *aesthetic appreciation?* The results of Experiment 1 and 2 indicate that abstract stimuli with
21 natural-like spatial frequencies are associated with higher aesthetic appreciation, increased
22 processing fluency and enhanced early attentional engagement. Such attentional modulation,
23 as indicated by present and previous evidence (Nadal, 2013; Spehar et al., 2015), seems to be
24 associated with optimal perceptual processing dynamics, indexed by greater activation in
25 early sensory areas (Calvo-Merino et al., 2008; Cupchik et al., 2009; Jacobsen et al., 2006;
26 Koelsch et al., 2006; Munar et al., 2009; Vartanian and Goel, 2004) and, in the present study,

1 by enhanced early electrophysiological responses. Crucially, these responses resulted to be
2 consistently correlated also with our conscious experience of beauty (Cupchik et al., 2009;
3 Graham and Redies, 2010; Massaro et al., 2012). To this respect, a relevant question arises:
4 why would aesthetic appreciation be preceded by and correlated with attentional enhancement
5 and greater bold and electrophysiological activations in sensory areas? Our results do not
6 provide a definitive answer to this question, but we can speculate that aesthetic appreciation
7 might serve as an evolutionary, hedonically marked, feedback over bottom up perceptual
8 processing dynamics (Chetverikov and Kristjánsson, 2016; Winkielman et al., 2003),
9 signaling the occurrence of specific stimulus features, valued as most informationally
10 profitable by the human nervous system (e.g., because of their high signal-to-noise ratio
11 which makes them more reliable; Consoli, 2015; Kesner, 2014; Koelsch et al., 2019; Van de
12 Cruys and Wagemans, 2011). In line with this interpretation, previous studies also suggested
13 that the brain generates intrinsic reward when it senses informationally profitable signals
14 (Oudeyer et al., 2007). Informational value per se was found to attract human attention (Baldi
15 and Itti, 2010; Itti and Baldi, 2009) and to correlate with the activation of dopamine-rich
16 midbrain reward-related structures (Schwartenbeck et al., 2016) which were also found to
17 underlie aesthetic appreciation (Blood & Zatorre, 2001; Cela-Conde et al., 2004; Kawabata &
18 Zeki, 2004). Accordingly, the attentional selection of informationally valuable auditory input
19 has been recently related with aesthetic pleasure in music (Koelsch et al., 2019).

20 In the case of the present study, the visual system might have “interpreted” *Background*
21 stimuli with a more natural spatial frequency content (i.e. a power spectrum approaching
22 natural images statistics), to which the human visual system has adapted (Pàrraga et al., 2000),
23 as less noisy (i.e. more informationally valuable) and consequently might have up-weighted
24 the incoming visual input (Ronga et al., 2017). Conversely, for stimuli diverging from natural
25 statistics, the visual input might have been down-weighted via a reduction in the system
26 excitability (Limanowski et al., 2018). Our electrophysiological data support this

1 interpretation. Alpha ERD, which we found to be more evident after the presentation of more
2 appreciated “natural” stimuli, has been shown to dynamically modulate the neural gain in
3 sensory areas (see Sigala et al., 2014 for a review). Moreover, early components of the VEP,
4 such as C1 and N1, have been suggested to reflect the attentional up-weighting of visual
5 inputs according to their estimated precision via modulations of the synaptic gain of
6 pyramidal cells (Brown and Friston, 2012). Finally, previous research (Higashi et al., 2017;
7 Mars et al., 2008; Ostwald et al., 2012) demonstrated that measures of informational value
8 correlate with trial by trial fluctuations of the P3 component that in our study was also found
9 to correlate with aesthetic appreciation. Regarding the interpretation of the present results, we
10 believe it is important to clarify that we do not hypothesize that an early aesthetic appreciation
11 causes and precedes visual sensitivity and electrophysiological and behavioural correlates of
12 attentional enhancement. On the contrary, we argue that aesthetic appreciation follows (i.e., is
13 a feedback of) increased visual sensitivity and attentional enhancement for more
14 informationally profitable stimuli.

15 Altogether the present data might be considered as evidence supporting the hypothesis that
16 aesthetic pleasure might represent an intrinsic reward allowing the system to spontaneously
17 engage in perceptual activities maximizing informational gain. Crucially, we are not arguing
18 that all aesthetic experiences can be explained by the attentional selection of informationally
19 profitable low-level stimulus perceptual features. Although this might be the case for the
20 abstract stimuli employed in our study, complex art products, such as music, literature and
21 figurative arts can induce aesthetic appreciation via content-based or purely contextual
22 variables (Koelsch et al., 2019) which are not considered in the present research.

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Highlights

- Abstract pictures with nature-like spatial statistics are more appreciated
- Targets embedded in more appreciated abstract pictures are faster to detect
- Aesthetic judgements correlate with attention-related evoked potential amplitude
- ERP indexes of perceptual learning are enhanced for more appreciated pictures
- Alpha event related desynchronization is increased for more appreciated pictures

Credit Author Statement

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