2013

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http://papers.ssrn.com/abstract=2321787

Summary: The interest of marketing science in using neuroscience techniques to understand the consumer's thought processes, dates back to the 1970s, when EEG data were recorded while subjects were watching TV commercials. Recently, fMRI was used to study the neural correlates of culturally based brands and neural predictors of purchases. These studies have discovered important properties of the neural circuits that are associated with consumer decision-making process and satisfaction. Here, EEG brain mapping was used to study the dynamics of the brain activity associated with these processes. The present study validated the EEG technology as an adequate neuromarketing tool and shows that consumer's satisfaction evaluation with the aesthetical dermatological treatment involved the activation of neural circuits involved with facial beauty evaluation.

Keywords: neuromarketing, consumer satisfaction, EEG mapping, decision-making modeling, aesthetic treatment

1 Introduction

The interest of marketing science in using neuroscience techniques to understand the consumer’s thought processes, dates back to the 1970s, when EEG data were recorded while subjects were watching TV commercials. (Young, 2002). Recently, fMRI was used to study the neural correlates of culturally based brands (Ambler et al., 2000; McClure et al., 2004; Schaefer et al., 2006 and Yoon et al., 2006) and neural predictors of purchases (Knutson et al., 2007).

The microeconomic theory states that purchases are driven by a combination of the consumer’s preference and price. Using event-related fMRI, Knutson et al. (2007) showed that activation of the nucleus accumbens correlated with the consumer’s preference, whereas excessive prices activated the insula and deactivated the medial prefrontal cortex prior to the purchase decision. Coke® and Pepsi® are nearly identical in chemical composition; however, humans routinely display strong subjective preferences for one or the other. McClure et al. (2004) showed that the anonymous delivery of Coke® or Pepsi® activated the ventromedial cortex, but, when knowledge about the brand was available, only Coke® and not Pepsi® activated the hippocampus, dorsolateral prefrontal cortex and the midbrain. They concluded that the consumer’s preference was a complex construct that involved judgments based on sensory information and the history of the relationship between the individual and the brand. Consumer preferences were, therefore, based on a history of customer satisfaction.

Although neuroscience has extensively examined the reward systems (Aktsuki et al., 2003; Bretier et al., 2001; Plat and Padoa-Schioppa, 2009; Polezzi et al., 2010; Roger et al., 2004; Tobler, Fiorillo and Schultz, 2005) involved in satisfaction assessment and preference encoding, the customer's brain activity associated with the evaluation of service satisfaction has not been elucidated. Therefore, we examined the brain activity of women by evaluating their satisfaction in using an aesthetic dermatological filler treatment (Arruda, Rocha and Rocha, 2008).

1.2 A Satisfaction study

Competition makes people worry about physical appearance, which occurs primarily with respect to aging of the face and skin. Studies analyzing attitudes toward aging and the elderly have found that older women are judged more negatively than older men because modern urbanized societies allow two standards of male beauty (Berman, O'Nan and Floyd, 1981; Deutsch, Zalenski and Clark, 1986; Sontag, 1972), those of the boy and of the man, but only one standard of female beauty, that of the girl. Thus, women are more prone to enroll in cosmetic dermatology procedures.

1.3 Facial recognition

Facial attractiveness is an important Darwinian factor in human reproduction and is an important social factor of motivated behavior (Aharon et al., 2001). In addition, facial recognition is important in human evolution because facial expressions are external signals of the internal experienced emotions (Britton et al., 2006b), and the emotional information exchange is fundamental to social relations. Because of its importance for human behavior, facial recognition is supported by a specific and diverse neural circuit involving a) regions of the extrastriate cortex that process the visual identification of individuals; b) the superior temporal sulcus, where gaze directions and speech related to movements are processed; c) the amygdala and insula, where facial emotional expression is processed; d) the fusiform face areas and superior temporal sulcus, where attractiveness, gender and age are identified; and e) regions in the prefrontal cortex and in the reward circuitry, such as the nucleus accumbens and orbitofrontal cortex, where the assessment of beauty is processed (Aharon et al., 2001; Britton et al., 2006a; Brady, Campbell and Flaherty, 2004; Ishai, 2007; Ishai, Schmidt and Boesiger, 2005; Kircher et al., 2001; Singer et al., 2004).

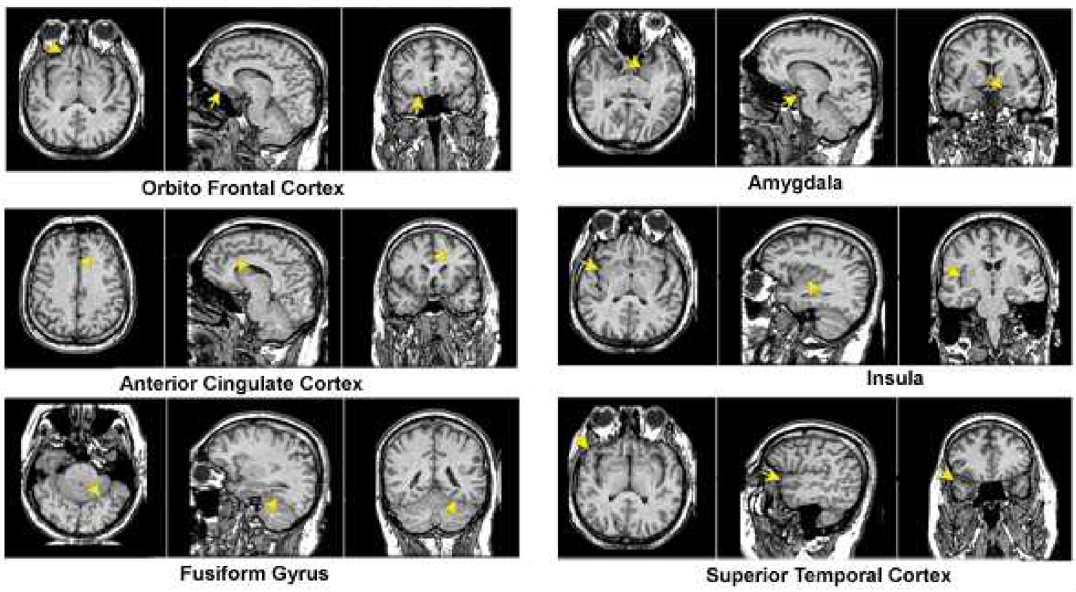

Figure 1 – Magnetic resonance images showing several neural structures involved in face processing.

Quiroga et al. (2005) have shown that specific neurons specialize in recognizing specific faces, which demonstrated the specificity of the facial recognition neural circuits

(FRNCs). All of these studies highlight the engagement of the FRNCs in deliberative and implicit social judgments. Figure 1 shows the location of some of the structures involved in these judgments.

Neuropsychological and functional neuroimaging studies frequently use facial expressions to probe brain regions involved in affect recognition such as the amygdala, the insula and the orbitofrontal cortex (O´Doherty et al., 2003). One feature of a face that can elicit a strong affective response is its attractiveness or beauty. Attractiveness impacts not only mating success, but also kinship opportunities, the evaluation of personality, performance and employment prospects (Cellerino et al., 2007; Ishai, 2007; Kranz and Ishai, 2006; Werheid, Schacht and Sommer, 2007). Functional magnetic resonance imaging (fMRI) studies have shown that a complex network involving different regions of the orbitofrontal cortex, the medial prefrontal cortex, the paracingulate cortices, the insula, the amydgala and the superior temporal cortex are involved in processing attractiveness (Ishai, 2007; Kranz and Ishai, 2006; Winston et al., 2007). More specifically, the orbitofrontal cortex, the amygdala and the insula are involved in sensing the value of social attractiveness (Winston et al., 2007).

The electroencephalogram (EEG) has also been used to study the temporal characteristics by which facial attractiveness is appraised. These studies have shown that facial analysis involves distinct steps, with early events correlating with the recognition of physical characteristics and later components being associated with emotional, gender and social information carried by facial expression (Cellerino et al., 2007; Werheid, Schacht and Sommer, 2007).

1.4 Investigating customer satisfaction with aesthetic dermatological treatments

Many people worry about physical appearances, mostly with respect to aging of the face and skin. This phenomenon has motivated new developments in cosmetic dermatology and the need for evaluating patients' levels of satisfaction with the new proposed treatments. Poll questionnaires have been used for such evaluations, and the analysis of the electroencephalogram mapping, which is obtained while the patient answers the satisfaction questionnaire, may cause the results to be less subjective (Arruda, Rocha and Rocha, 2008).

Because patients should be allowed free time for answering pool questions, the EEG analysis has to examine the brain activity preceding the moment the patient provides the answer. In contrast, previous studies involving EEG and decision-making focused on the analysis of brain activity following the decision-making or stimulus presentation (Chen et al., 2009; Polezzi et al., 2010; Utku et al., 2002). Rocha et al. (2010) examined vote decision-making and used an EEG brain mapping technique, which considered the brain to be a distributed processing system (Foz et al., 2001; Rocha, Massad and Pereira Jr., 2004; Rocha et al., 2005; Rocha et al., 2010 and Rocha, Rocha and Massad, 2011). Using this approach, Rocha and colleagues (2010), for instance, were able to disclose different patterns of brain activity associated with different voting decisions. In a similar vein, we used the same EEG mapping technique to investigate the brain activity associated with customer satisfaction.

The purpose of the present paper is to extend the analysis on consumer satisfaction reported by Arruda et al (2008) by studying brain mappings associated with level of satisfaction with treatment and self-evaluation of face components before and after treatment.

2. Methods

2.1 The EEG brain mapping of a cosmetic dermatology treatment

Hyaluronic acid (HA) was used to correct nasolabial folds and in lip augmentation in 33 women aged 30 to 55 years with a mean age of 44 years. At the initial evaluation, patients were inspected for nasolabial fold depth and lip volume loss. Informed consent was obtained from all patients before treatment, and the experimental protocol was approved by the Ethics Research Committee of the Catholic University of Campinas. Treatment consisted of an injection of 1.0 ml of HA in each nasolabial fold or in the upper and lower lip. This procedure was performed under local anesthesia or infraorbital nerve blockage. Patients were reevaluated at 48 hrs and 1, 2 and 3 months after the initial procedure. The reevaluation detected the side effects and assessed the treatment durability.

2.2 The experiment

At the third-month evaluation, two networked personal computers were used to record the EEG and present the patients with a questionnaire about:

1) the self-evaluation of face components: hair, forehead, eyebrows, eyes, nose, chin, facial contours, cheeks and neck, which were classified as superb, great, regular, bad or very bad (F).
2) the reasons for deciding to undergo the treatment. Patients selected from one or more of the following options**:** *because it was a free treatment; because she was dissatisfied with her appearance; because she had already planned to submit herself to an aesthetic treatment; because it was recommended by a friend; none of these.*
3) the level of satisfaction with the results of the treatment by comparing *before and after* photos and declaring the patient *very satisfied, satisfied, unsatisfied, very unsatisfied, or none of these* (A) .
4) the self-evaluation of appearance after the treatment: *very much improved, improved, did not change, worsened or badly worsened* (R).
5) how the patients' family, friends and coworkers evaluated the results of the treatment: *excellent, good, bad, very bad, no opinion*.
6) the decision to repeat the treatment: *definitely yes, yes, no, definitely no, undecided*.
7) the decision to recommend the treatment to other people: *definitely yes, yes, no, definitely no, undecided.*

Regression analysis was used to disclose possible associations between the answers to different items on the questionnaire. The correlation entropy $\mathbf{h(c_i)}$ of the EEG activity recorded while answering the questionnaire was calculated, as described by Rocha et al. (2004, 2005, 2010, 2011), for each electrode $\mathbf{e_i}$ of the 10/20 system and for each item of the questionnaire (see appendix 1 for a full description of the EEG methodology). Regression analysis was used to study the correlation between the type of answer for each questionnaire item and the associated **$h(c_i)$.** The values of the angular coefficients for the calculated linear regression were color-coded to build the regression EEG mappings (Figure 2) associated with each questionnaire item.

3 Results

3.1 The poll data

Table 1 shows what patients liked most of their facial components (questionnaire item 1 - EEG mappings F in Figures 1 and 2). Eyes and hair were the preferred elements, and the forehead, eyebrows, nose and neck had the highest rate of disapproval. We recoded the facial component evaluation according to the following rule: Superb (S) = 5, Good (G) = 4, Regular (R) = 3, Bad (B) = 2 and Very Bad (VB) = 1, and we calculated a general appearance index for each patient as the mean of her evaluation of all facial components. The mean general appearance index calculated for all patients was **4,07**. Hence, the majority of the patients considered themselves to be attractive.

Table I – Face components evaluation

	hair	forehead	eyebrows	eyes	nose	cheeks	ears	lips	chin	neck	contour
S	15	8	12	8	0	4	0	15	0	0	12
G	65	50	54	71	54	50	73	58	65	35	46
R	0	0	0	9	8	12	15	12	19	8	19
B	20	12	8	8	35	34	8	15	12	46	23
VB	0	30	26	4	3	0	4	0	4	11	0

S: Superb; G: Great; R: Regular; B: Bad and VB: Very bad. Data are presented as a percentage.

Patients decided to undergo the treatment (questionnaire item 2) because they were already considering it (54%) or dissatisfied with their lips or nasolabial folding (52%). The fact that the treatment was free of charge did not influenced patient's decision

Patients were very satisfied or satisfied with the results of the treatment (questionnaire item 3 – EEG mappings R in Figures 1 and 2) and with their *facial attractiveness* after the treatment (questionnaire item 4 – EEG mappings A in Figures 1 and 2). No patient claimed to be unsatisfied with both the immediate and later treatment results. In addition, patients declared that family and friends made highly positive comments about their new appearances (questionnaire item 5). Therefore, patients were firmly determined (60%) or determined (32%) to repeat the treatment (questionnaire item 6) and to recommend it (questionnaire item 7) to family (70%), friends (60%) and others (30%).

3.2 The Brain Mappings

The mean entropy mapping values calculated for each of the studied EEG epoch are shown in Figure 2 with the corresponding Z score mappings (Appendix 1). The minimum Z score obtained for all mappings was 1.979, which invalidated the null hypothesis that the entropy values could be due to chance.

The minimum values for the calculated mean entropies were obtained for the occipital electrodes O_1, O_2 and O_z for all of the studied EEG epochs (Table 2). The maximum values of the calculated mean entropies were obtained for the electrodes F4, F8, CZ, C4 and T4 for all of the studied EEG epochs (Table 2). The minimum Pearson's correlation coefficient obtained for comparing the mean entropy mapping values was 0.93, confirming that all 3 mappings were very similar.

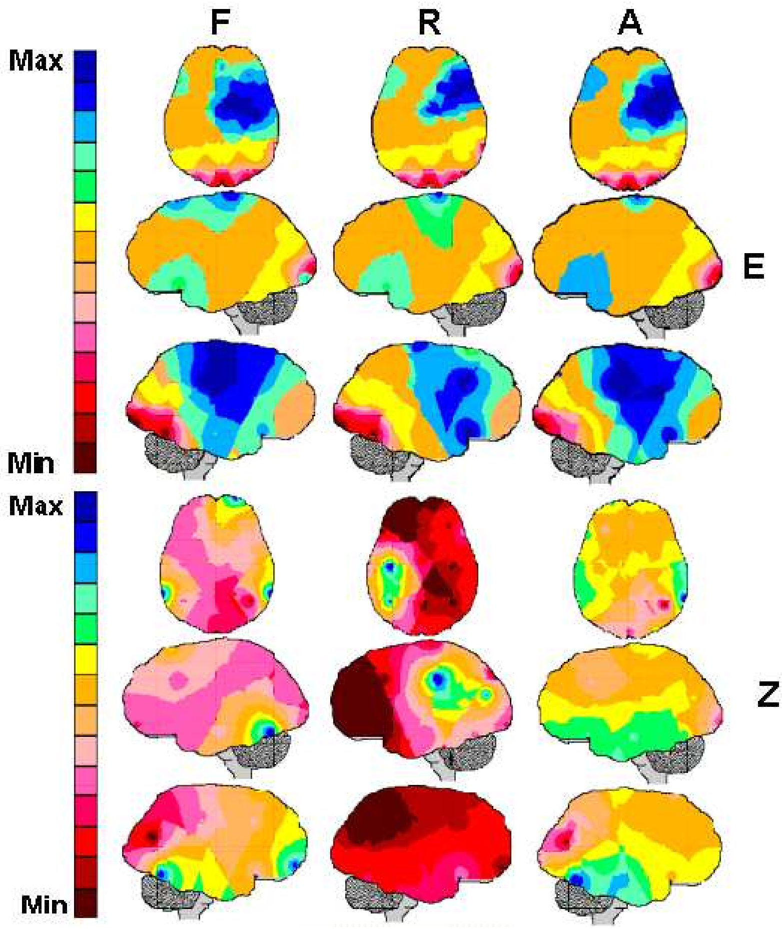

Figure 2 – Mean entropy brain mapping (E) associated with *facial self-evaluation* (F), *satisfaction evaluation* of the results (R) and *attractiveness self-evaluation* (A) and the Z score mapping (Z).

The regression analysis results showed that Holm-Bonferroni and FWER procedures were equivalent in selecting the most significant statistical inferences, as shown in Table 2. Back-wise regression was found to be more conservative than forward-wise regression, and it may enhance type III error frequency. Therefore, the forward-wise inferences found to be significant according to the FWER procedure (marked in red in Table 3) were used to build the brain mapping shown in Figure 3.

Table 2 – Entropy statistics

	F		R		A	
	Mean	**Std.Dev.**	**Mean**	**Std.Dev.**	**Mean**	**Std.Dev.**
C3	6.55	2.53	7.15	2.10	6.58	2.53
C4	6.90	2.36	7.20	1.75	6.98	2.19
CZ	6.83	2.49	7.37	1.85	6.86	2.36
F3	6.42	2.19	6.79	1.99	6.30	2.35
F4	6.75	2.45	7.49	1.66	6.89	2.35
F7	5.97	2.39	6.60	1.98	6.10	2.28
F8	6.73	2.66	7.50	1.84	6.93	2.52
FP1	6.35	2.15	6.90	1.72	6.44	2.16
FP2	6.24	2.29	6.76	1.83	6.37	2.23
FZ	6.75	2.23	7.05	1.80	6.77	2.18
O1	5.72	3.48	5.61	3.40	5.73	3.46
O2	5.44	3.28	5.44	3.24	5.44	3.25
OZ	5.53	3.33	5.45	3.30	5.54	3.33
P3	6.39	2.54	6.84	1.86	6.45	2.47
P4	6.50	2.22	6.75	1.70	6.48	2.12
PZ	6.45	2.27	6.68	1.76	6.53	2.16
T3	6.42	2.46	6.91	2.03	6.52	2.40
T4	6.67	2.55	7.11	2.04	6.72	2.41
T5	6.53	2.53	7.00	2.07	6.50	2.55
T6	6.51	2.29	6.66	2.71	6.65	2.26

The regression brain mapping values associated with the facial component self-evaluation, treatment results and the self-evaluation of appearance after the treatment are shown in Figure 3. The $\mathbf{h(c_i)}$ calculated for the central (FZ, CZ and PZ) and right (FP2, T4 and P4) electrodes (green to blue electrodes in Figure 2F) was positively correlated with the facial component of self-evaluation, such that a high $\mathbf{h(c_i)}$ at these electrodes was associated with a very positive self-evaluation (Max = 5). In contrast, the $\mathbf{h(c_i)}$ calculated for the left (F3, F7, C3, P3 and T5) and right frontal (F4 and F8) electrodes (rose to dark red electrodes in Figure 2F) was negatively correlated with the facial component of self-evaluation, such that a high **h(c_i)** at these electrodes was associated with a positive self-evaluation (Min = 4).

Table 3 – Angular coefficients ($\bar{b}$) and their statistical significance (p) for the regressions used to obtain the EEG mapping values in Figure 2. The statistically significant p based on the FWER procedure is shown in red.

	F		R		A	
	$\bar{b}$	p	$\bar{b}$	p	$\bar{b}$	p
C3	0.3363	0.0166	-0.0230	0.6689	0.4598	0.0081
C4	-0.0344	0.7093	-0.2452	0.0322	-0.3050	0.0316
CZ	-0.2165	0.0060	-0.3622	0.0007	-0.3214	0.1868
F3	0.3610	0.0000	-0.2620	0.0003	-0.4456	0.0095
F4	0.4165	0.0000	-0.8284	0.0000	-0.1021	0.6973
F7	0.2857	0.0000	-0.0870	0.0540	0.1553	0.1055
F8	0.5271	0.0000	0.4088	0.0032	0.5323	0.0362
FP1	-0.0534	0.4255	0.3037	0.0018	-0.4322	0.0456
FP2	-0.3182	0.0000	0.0844	0.3773	0.4278	0.0316
FZ	-0.4143	0.0000	-0.0072	0.9348	0.0699	0.6613
O1	-0.1035	0.0002	0.0590	0.1369	0.1294	0.1719
O2	0.2495	0.0000	-0.0197	0.5931	0.1855	0.0392
OZ	-0.0810	0.0024	-0.2029	0.0000	-0.0782	0.4126
P3	0.1875	0.0012	-0.3408	0.0000	-0.0012	0.9943
P4	-0.1616	0.0308	0.3843	0.0001	-0.3195	0.0390
PZ	-0.2618	0.0000	0.6696	0.0000	0.6001	0.0001
T3	-0.4515	0.0000	-0.1887	0.0277	0.2269	0.2449
T4	-0.5192	0.0000	0.1818	0.0215	-0.3742	0.0376
T5	0.4243	0.0000	0.1757	0.0675	0.0974	0.6441
T6	-0.2110	0.0000	0.1509	0.0001	0.0762	0.3896
R^2	44%		20%			57%
	F/R		F/A		R/A	
Pc	0,1		0		0,46	

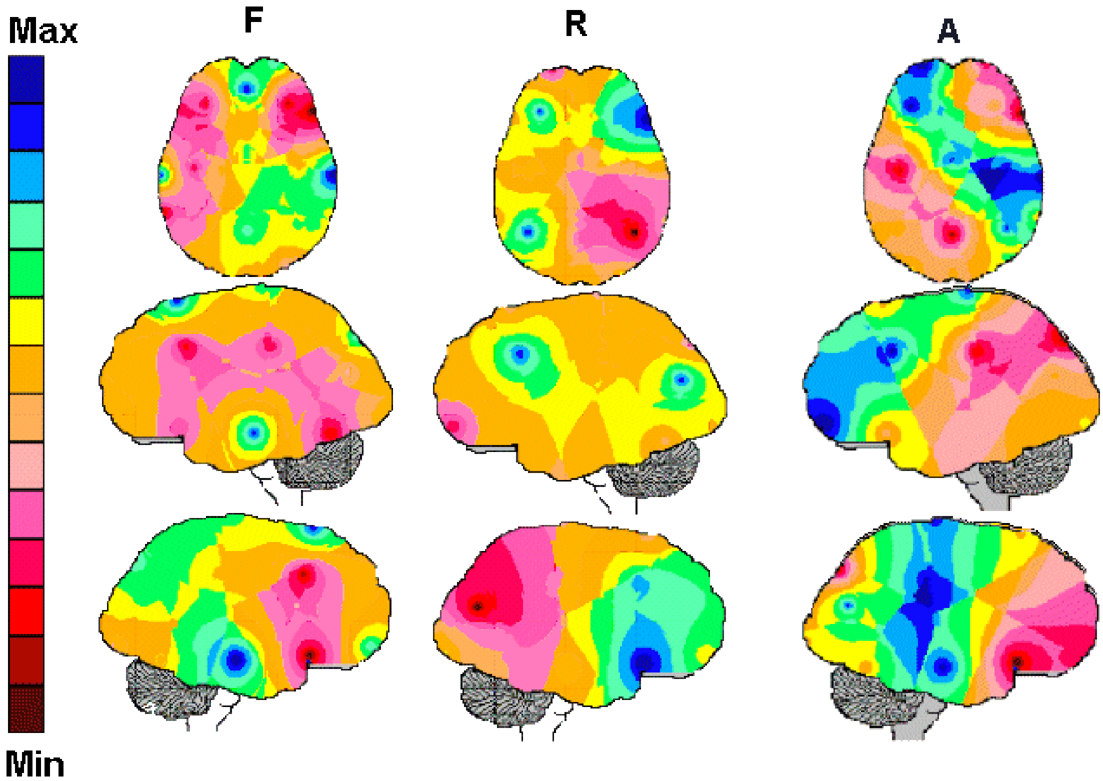

Figure 3 – Regression mapping values $D = a + b_1 h(c_1) + ... + b_{20} h(c_{20})$ calculated for all volunteers, such that negative values of b_i were color-coded from rose to dark red, positive values of b_i were color-coded from yellow to dark blue, and those $b_i = 0$ were color-coded as orange. The correlation entropy $h(c_i)$ calculated for the electrodes e_i^- associated to negative b_i contributed to make D →Min, whereas $h(c_i)$ calculated for the electrodes e_i^+ associated to positive b_i contributed D →Max. For the facial element component of self-evaluation (**F**), Max = 5 (for *Superb*) and Min = 1 (for *Very bad*). For the satisfaction with the treatment results (**R**), Max = 5 (for *Very satisfied*) and Min = 4 (for *Satisfied*), and for the attractiveness self-evaluation after treatment (**A**), Max = 5 (for *Superb*) and Min = 3 (for *regular*). The computed values of b_i, their statistical significance p and the computed R^2 for each regression are shown in Table 3. The similarity between the mapping values, as evaluated by the Pearson's coefficient (Pc), is shown in Table 3.

Before and after photo comparison was positively associated with the **h(c_i)** that was calculated from the F3, P3, FZ, F4 and F8 electrodes (green to blue electrodes in Figure 2R), implying that a high **h(c_i)** was associated with a very positive evaluation (Max = 5). In contrast, the **h(c_i)** calculated for the electrodes FP1, P4, CZ, C4 and PZ was negatively associated (rose to dark red electrodes in Figure 2R) with *the before and after decision,* where a high **h(c_i)** was associated with a positive evaluation (Min = 4).

Finally, the patients' self-evaluation of their appearance was positively correlated with the **h(c_i)** calculated for the electrodes FP1, F3, CZ, P4 and T4 (green to blue electrodes in Figure 2A), such that the high values of **h(c_i)** were associated with a highly positive appearance (Max = 5). In contrast, **h(c_i)** calculated for the electrodes FP2, F8, C3 and PZ (rose to dark red electrodes in Figure 2A) was negatively correlated with the patient' self-evaluation, such that the high values of **h(c_i)** were associated with a regular appearance (Min = 3).

4 Discussion

Beauty is strongly influential in human reproduction and socially motivated behaviors (Aharon et al., 2001), and it is more important for women than for men. Also, women are judged more critically than men concerning aging because modern urbanized societies allow only one standard of female beauty, that of the girl (Berman, O'Nan and Floyd, 1981; Deutsch, Zalenski and Clark, 1986; Sontag, 1972). Finally, beauty is the result of both self-evaluation and social recognition. The female's sense of her own beauty is determined by the feeling she has about herself and the cumulative opinions of her partner, family and friends.

In this study, the volunteers were satisfied or very satisfied with the components of their faces, and the EEG mapping values showed that this evaluation was supported by a diverse set of neurons, where their activity was recorded by a large number of electrodes (Figure 2).

The present results were consistent with those of previous studies showing that facial recognition was supported by a specific and diverse neural circuit (Aharon et al., 2001; Britton et al., 2006a; Brady, Campbell and Flaherty, 2004; Ishai, 2007; Ishai, Schmidt and Boesiger, 2005; Kircher et al., 2001; Singer et al., 2004). The **$h(c_i)$** values calculated for the left and right anterior frontal electrodes were inversely correlated with this self-evaluation, and the values obtained for the right posterior electrodes were directly correlated with a very positive classification of patients' facial elements. Previous studies have shown that the left hemisphere was focused on self-evaluation of the body and the right hemisphere with perception of other people's bodies (Alisson, Puce and McCarthy, 2001; Brady, Campbell and Flaherty, 2004; Ishai, Schmidt and Boesiger, 2005; Kircher et al., 2001; Stone and Valentine, 2005).

Because female beauty is determined by the feelings that females have about themselves and socially collected opinions, we would propose that the left brain contributes to the self component and the right brain encodes the social component of the volunteers' evaluation of their beauty. If this is true, then the present results suggest that the self component reduced a more positive social evaluation of the volunteer's beauty. In addition, the patients were dissatisfied with the age effects on their looking and motivated to undergo the aesthetic treatment. Therefore, it may be concluded that aging creates a necessity to *remedy decaying beauty*, which, in turn, motivates the search for an aesthetic treatment.

The volunteers were asked to compare their pre- and post-treatment photos and to decide if their attractiveness was improved or worsened. They were unanimous in deciding that the treatment improved or very much improved their appearance. The *very much improved* decision was supported by the increase in the $\mathbf{h(c_i)}$ calculated from electrodes F8, F4, F3, and P3 (green to blue electrodes in Figure 2R), whereas the high values of $\mathbf{h(c_i)}$ at P4, C4, CZ and PZ (rose to dark red electrodes in Figure 2R) reduced their enthusiasm with the treatment results. A comparison of Figures 2F and 2R showed a reversion of the correlation between $\mathbf{h(c_i)}$ for the left electrodes and attractiveness self-evaluation. Before the treatment, the left hemisphere contributed to a less positive decision about the attractiveness of the components of the facial elements, whereas the high values of $\mathbf{h(c_i)}$ at the left electrodes F3 and P3 were associated with the *very much improved* decision after the treatment. The only difference in the right hemisphere was the reversion of the correlation between the $\mathbf{h(c_i)}$ and decision-making, where the frontal electrodes became associated with the more positive evaluations and the posterior electrodes correlated more to the less positive evaluations made after the treatment than before the treatment.

If the left hemisphere was more concerned with self-evaluation, then these results showed that the volunteers were more positive about their appearance after the treatment, and the social evaluation remained unchanged. Therefore, the analysis of the brain activity during these different decisions supports the “subjective” poll opinion.

The very positive self-evaluation of patients’ appearances after the treatment (questionnaire item 4) was associated with the high values of $\mathbf{h(c_i)}$ calculated from the anterior left and posterior right electrodes (figure 2A). This supports the hypothesis that the positive evaluation from the treatment was due both to personal and social factors. This finding is in agreement with the fact that the left hemisphere contributed more to a more positive appearance self-evaluation after than before the treatment and with the high satisfaction of family and friends with the volunteer's new appearance. Because the patients were very decided about repeating the treatment and to promote it among family and friends, we concluded that their satisfaction with the results of the aesthetic intervention translated into trust. Whether trust was solely correlated to the treatment technique, or it is inputted to the physician's abilities remains to be investigated.

Appendix 1 – The EEG mapping technology

Two networked personal computers were used to record the EEG and another for sequentially displaying the questionnaire items (Figure 3). The volunteers were allowed to take as much time as needed to make a decision. The times at which the questionnaire item was displayed (**t_q**) and at which the decision was made (**t_d**) were recorded. The EEG was visually inspected for artifacts before its processing, and the EEG epochs associated with a bad EEG were discarded (e.g., when eye movements could compromise the results of regression analysis). The linear correlation coefficients $r_{i,j}$ for the activity at each recording site e_i that referred to the activity for each of the other 19 electrodes e_j were calculated for the EEG epoch ($t_d - t_q$) of each decision, which was used to select the EEG sequence to calculate the correlation entropy $h(c_i)$ (Foz et al., 2001; Rocha, Massad and Pereira Jr., 2004; Rocha et al., 2005; Rocha et al., 2010 and Rocha, Rocha and Massad, 2011) as:

$$h(r_{i,j}) = -r_{i,j} \log_2 r_{i,j} - (1 - r_{i,j}) \log_2 (1 - r_{i,j}) \qquad (1)$$

$$\bar{r}_i = \frac{\sum_{1}^{19} \bar{r}_{i,j}}{19} \qquad (2)$$

$$h(\bar{r}_i) = -\bar{r}_i \log_2 \bar{r}_i - (1 - \bar{r}_i) \log_2 (1 - \bar{r}_i) \qquad (3)$$

$$h(c_i) = \sum_{1}^{19} h(\bar{r}_i) - h(r_{i,j}) \tag{4}$$

It may be stressed that we did not intend to assign any physiological meaning to the entropy $h(c_i)$**.** The correlation entropy $h(c_i)$ was assumed to be a measure of the uncertainty about the existence of a correlation between the activity recorded by pairs of electrodes e_i, e_j**.** The entropy $h(r_{i,j})$ is equal to 1 when $r_{i,j} = 0.5$ and equal to 0 when $r_{i,j} = 0$ or $r_{i,j} = 1$. Thus, $h(r_{i,j})$ measures the uncertainty of the correlation between the EEG activity recorded by e_i, e_j**.** The entropy $h(\bar{r}_i)$ of the mean correlation **ŕi** provides more information about the covariance of the correlation between the activity recorded by e_i and all other e_j. If $r_{i,j} = 0.5$ for all e_j, then $\bar{r}_i = 0.5$ and $h(\bar{r}_i) = 1$. Also, if $r_{i,j} \to 0$ for some e_j, $r_{i,j} \to 1$ for some other e_j and $r_{i,j} \to 0.5$ for the remaining e_j, then $\bar{r}_i = 0.5$ and $h(\bar{r}_i) = 1$. However, if $r_{i,j} \to 1$ ($r_{i,j} \to 0$) for most of the e_j, then $\bar{r}_i = 1$ ($\bar{r}_i = 0$) and $h(\bar{r}_i) = 0$. All other conditions imply $h(c_i) \to 0$. Therefore, the actual value of $h(c_i)$ is a measure of how much the EEG activity recorded by the electrode e_i may be associated with the task being processed by the brain.

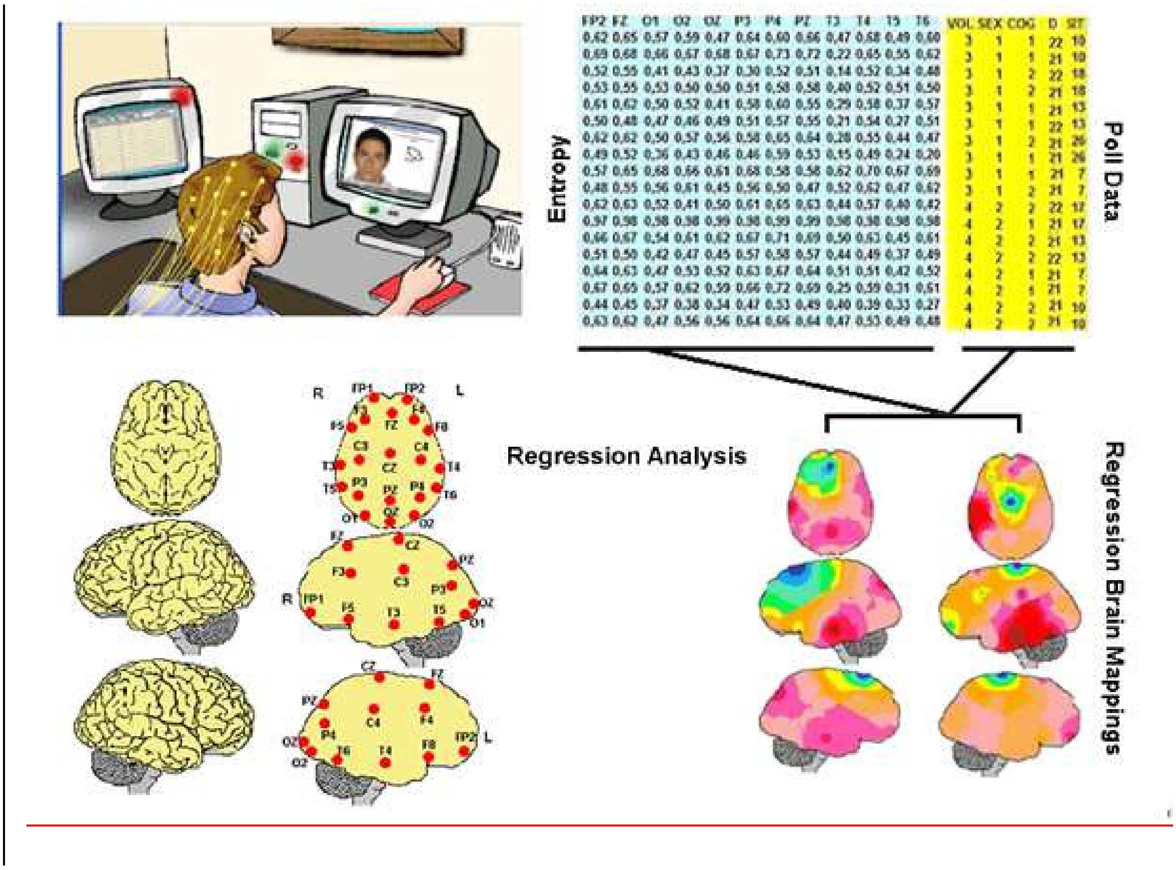

Figure 4 – Outline of the experiment. Two networked microcomputers were used to record the EEG activity (10/20 system) while the volunteer decided about a questionnaire item. The beginning of the questionnaire item was displayed, and the moment a decision was made, data were saved in the database together with the type of decision-making and time required to achieve the decision. The linear correlation coefficients $r_{i,j}$ for the recorded activity at each recording electrode e_i referred to the recorded activity for each of the other 19 recording sites e_j that were calculated for each questionnaire item and volunteer. These $r_{i,j}$ were used to calculated the correlation entropy $h(r_i)$ for each recording electrode e_i . Therefore, $h(r_i)$ was calculated for all 20 recoding electrodes. The corresponding values of $h(r_i)$ constituted the entropy data base. Regression analysis concerning the decision about each questionnaire item and the $h(r_i)$ was used to create the cognitive brain mapping values. Each mapping image shows the contribution of the product $\beta_i * h_m(r_i)$ of each electrode e_i to the decision made. The $h_m(r_i)$ is the average of the $h(r_i)$ calculated for all volunteers. The location of each 10/20 system electrode is displayed at the left brain drawings.

A null hypothesis was constructed by randomly reordering the EEG channels, i.e., the mean entropy was recomputed from a *hypothetical brain* obtained by randomly shuffling the EEG recorded activity from the individuals. Next, the Z scores between the mean entropy and the null hypotheses were computed for each of the EEG epochs (facial evaluation – F, results satisfaction evaluation – R and attractiveness self-evaluation – A). The mean entropy calculated for each channel was used to generate the mean entropy brain mapping values shown in Figure 2, and the corresponding Z scores were used to generate the Z score mapping values. The minimum Z core for all of these calculations was 1.979, showing that the null hypotheses were rejected for all EEG epochs.

Linear regression analysis was used to study the correlation between the $h(c_i)$ and the response time $ST = t_s - t_q$, and, the logistic regression analysis was used to study the correlation between the $h(c_i)$ and P_2 (adequate) or $\bar{P}_2$ (not adequate) decision. The normalized values of the $b_i h(c_i)$ were used to build the color-coded brain mapping images to display the results of the regression analysis. The color-coding routine used commercial software. Statistically positive betas were coded from green (normalized $b_i h(c_i)$ tending to 0) to dark blue (normalized $b_i h(c_i)$ tending to 1). Statistically negative $b_i h(c_i)$ are displayed from rose (normalized $b_i h(c_i)$ tending to 0) to dark red (normalized $b_i h(c_i)$ tending to -1), and statistically non-significant $b_i h(c_i)$ are shown in orange. Brain contours are used as references for the spatial location of the 10/20 system electrodes.

Let p be the probability that the null hypothesis for a statistical inference is true. A statistical inference is assumed to be true if the value of p is less than a given significance threshold α, which is considered the maximum permissible error in making the inference. The threshold $\alpha = 0.05$ is commonly used for single inferences because the inference is not due to chance alone at least 95 times out of 100. The risk of declaring significant what is not is, at most, 5 times out of 100.

The analysis becomes complicated for multivariate inferences because the total possible error $\bar{\alpha}$ is dependent on the number n of inferences (Benjamin et al., 2001; Blakesley et al., 2009; Genovese et al., 2002; Huizenga et al., 2007; Marroquin et al., 2011; Nandy and Cordes, 2007; Vechiato et al., 2010). For statistical inferences supported by independent variables, the possible error is multiplied by n because, for each inference, the risk of its being wrong is 5%. The total possible error is, therefore, $\bar{\alpha} = n\alpha$, which implies that the certainty of making a wrong inference increases as the number of inferences increases. The solution is to decrease the value of α to minimize the total possible error. Bonferroni proposed α to be $1/n$ of the total admissible error $\bar{\alpha}$. Because the Bonferroni procedure may be too conservative and may increase the type II error, the Holm-Bonferroni method has been commonly used instead. However, when the independence hypothesis can be removed, $\bar{\alpha} < n\alpha$. In this condition, α may be greater than $1/n$ of the total admissible error $\bar{\alpha}$. As the correlation between the variables increases, the FWER calculation as $\alpha \le 1-(1-\bar{\alpha})^n$ maintains the level of possible total error at around $\bar{\alpha}$.

The entropies calculated for the 10/20 electrodes are dependent measurements. This condition is because both the Holm-Bonferroni and FWER methods were used to calculate the significance of the statistical inferences about the volunteer’s evaluations and the EEG activity, as measured by $\mathbf{h(c_i)}$.

Stepwise regression includes regression models in which the selection of predictive variables is performed by an automatic procedure. Commonly, a sequence of F-tests is used. Stepwise regression is another tool available to find the best relevant statistical inferences. Forward selection (forward-wise regression), which involves starting with no variables in the model and testing the variables individually and including them if they are 'statistically significant. Backward elimination (back-wise regression), which involves starting with all candidate variables and testing them individually for statistical significance and deleting any that are not significant. Stepwise regression is used for selecting the most useful statistical inferences in neurosciences (Antonakis and Dietz, 2011; Mueller et al., 2011; Song et al., 2008; Stadler et al., 2007), and it will be used here for the same purpose.

We combined stepwise regression, the Holm-Bonferroni and the FWER methods to select the most relevant statistical inferences between the EEG activity and the volunteers’ poll evaluations.

The Pearson’s correlation coefficient was calculated to provide an index of similarity between both the mean entropy and the regression brain mapping values obtained for each of the studied EEG epochs.

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