A NeuroMarketing Study of the Consumer Satisfaction

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This paper is an extended version of the paper Arruda, L. H. F., F. T. Rocha and A. F. Rocha, Studying the satisfaction of patients on the outcome of an aesthetic dermatological filler treatment Journal of Cosmetic Dermatology (2008) Vol: 7(4) Page: 246-250

Summary: The interest of marketing science on neurosciences technique started in the 70s, when the electroencefalogram (EEG) was recorded while subjects were watching TV commercials, and recently revived when function magnetic resonance was used to study the neural correlates of culturally based brands. These studies disclosed some important properties of the neural circuits supporting consumer decision-making and satisfaction. Here, a model is proposed concerning decision making and brand satisfaction about aesthetical treatment. EEG brain mapping was used to study the brain activity associated with such processes. The results validate the EEG technology as a neuromarketing tool and supports the proposed theoretical.

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

INTRODUCTION

The interest of marketing science in using neurosciences technique to understand the consumer's mind begun in the 70s, when the EEG was recorded while subjects were watching TV commercials (see Young, 2002). This interest was recently revived when 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).

Microeconomic theory sustains that purchases are driven by a combination of 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, while excessive prices activated the insula and deactivated the mesial prefrontal cortex prior to the purchase decision. Coke® and Pepsi® are nearly identical in chemical composition, yet humans routinely display strong subjective preferences for one or the other. McClure et al (2004) showed that anonymous delivery of Coke or Pepsi activates the ventromedial cortex, but when knowledge about the brand is available, only Coke® but not Pepsi® activates hippocampus, dorsolateral prefrontal cortex and the midbrain. They concluded that consumer's preference is a complex construct that involves, besides judgment based on sensory information, the history of relationship between the individual and the brand. Consumers may pay higher prices for their brand preferred products, because brands can be defined as culturally based symbols that promise certain advantages of a product to the customer (e.g., Chaudri and Holbrook, 2001, Schaefer et al, 2006). This uniqueness may derive from greater trust in the reliability of a brand or from more favorable affect when customers use the brand (Ambler, Ioannides and Rose, 2000). In the attempt to understand brand trust, Schaefer et al (2006) reported activation of a single region in the medial prefrontal cortex related to the logos of the culturally familiar brands, and questioned if differences in social values could be the explanation for the disagreement between their results and McClure's findings. In addition, Yoon et al (2006) proposed that activation of the medial prefrontal cortex is greater during personal judgment than during brand judgments, and that activation of the left inferior prefrontal cortex during brand judgments is greater than during personal judgments. Schaefer et al (2006) proposed that a better modeling of the consumer decision-making process is needed to point the relevant questions to be addressed by neuromarketing studies.

According to Ernst and Paulus (2005) decision making refers to a three-stage process of forming preferences, selecting and executing actions as well as evaluating outcomes. Rocha et al (2008) expanded this model by assuming that decision making requires 6 stages. In stage 1, a necessity η is identified based on information provided by sensory systems or stored in the memory. In stage 2, η generates a *motivation* ϑ to select and implement actions a_i that are expected to produce or obtain a good or service $\Gamma(a_i)$ that fulfills η. Actions a_i are selected during stage 3 according to preferences calculated from their expected benefits and costs for producing or obtaining $\Gamma(a_i)$. Execution and eventual adjustment of the planned actions occur in stage 4. In stage 5, the outcome is compared to the expected benefits and costs, generating a degree of satisfaction or displeasure, depending on the obtained benefits and costs. Finally, during stage 6, beliefs about a_i, as a solution for η, are updated taking into account the outcome evaluation. If satisfaction was achieved then future expected rewards for a_i are increased, otherwise costs associated to a_i will be enhanced. Doney and Cannon (1997) suggest that the construct of trust on brands involves a "calculative process" based on the ability of an object or party (e.g., a brand) to continue to meet its obligations and on an estimation by the other party (e.g. the consumer) of the costs versus rewards of staying in the relationship. Therefore, brand trust depends on a history of consumer satisfaction.

A Satisfaction Study

Many factors contribute to extend productive life in the modern world. Competition makes people worry about physical appearance, mostly in respect to facial and skin aging. Studies analyzing attitudes towards aging and the elderly have often 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) : the boy and the man, but only one standard of female beauty: the girl. Because of this, women are more prone to enroll in cosmetic dermatology procedures. Therefore:

1) in stage 1, aging creates a necessity η for remedying wrinkles, nasolabial folding, thinning of the lips and flattening of the upper lip (Coleman and Grover; 2006) that
2) in stage 2, motivates ϑ women to enroll in cosmetic dermatology treatment.

HA is one of many substances ($\Gamma(a_i)$) used as fillers to correct these problems (Lemperle, Morhenn and Charrire, 2003), such that

3) in stage 3, they may evalute filling with $\Gamma(a_i)$ as the remedy for η, taking into account the treatment financial cost and health risks versus the possible benefits of improving their facial appearance, and eventually
4) in stage 4, they undertake the cosmetic treatment and monitor the results.

Filling treatment results in initial face edema that makes facial appearance worse but improves in the first weeks, and provides an adequate correction of nasolabial folding, thinning of the lips and flattening of the upper lip (Coleman and Grover; 2006). Instructed about this treatment time evolution,

5) in stage 5, patients evaluate the results of filling treatment, comparing their expectations with their actual facial appearance and social (e.g., family, friends, work colleagues) judgment.

Because filling treatment is temporary,

6) in stage 6, the patient´s degree of satisfaction influences her trust (as a personal and social construct) in the aesthetical treatment, which in turn determines her decision to repeat it.

Face recognition

Human evolution can be viewed in terms of the species increasing ability to function effectively within a social context, because the brain evolved a specialized ability for social cognition (Singer et al, 2004). Theory of Mind (ToM) as the ability to attribute mental states to others has an important role in social cognition. Brain imaging studies in healthy subjects have described a brain system involving medial prefrontal cortex, superior temporal sulcus and temporal pole in ToM processing (e.g., Frith and Frith, 2003; Gallagher et al 2002; Hamilton, et al 2006; den Ouden et al, 2005). Aldolphs (2003) extended this proposal differentiating higher-order sensory cortices such as fusiform gyrus and superior temporal sulcus involved in detailed perceptual processing with the amygdale, ventral striatum, and orbitofrontal cotex linking sensory representations of stimuli to their motivational value. Figure 1 shows the location of some of these structures. Anterior cingulated cortex as well as insula are also associated with feeling states that reflect representation changes in bodily states arising from processing emotion-eliciting stimuli (Ernst and Paulus, 2005; Kuhnen and Knutson, 2005; Knutson et al, 2007; Paulus and Frank; 2006).

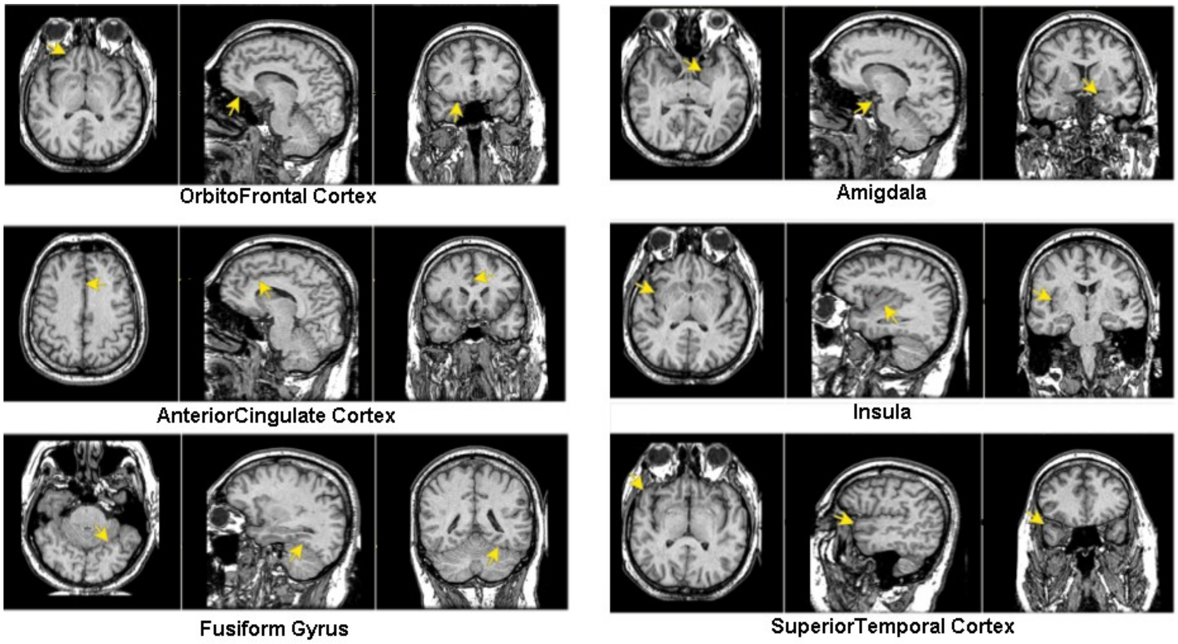

Figure 1 – Magnetic Resonance Images showing some of the neural structures discussed in the text.

Face recognition is also an important issue in human evolution because facial expressions are external signals of the internal experienced emotions (e.g., Britton et al, 2006), and emotional information exchange is fundamental in social relations. In addition, face attractiveness is an important Darwinian factor in human reproduction and an important social factor of motivated behaviors (Aharon et al, 2003). Because of its importance for human behavior, face recognition is supported by a specific and widespread neural circuit involving a) regions of the extrastriate cortex that process the identification of individuals; b) the superior temporal sulcus, where gaze directions and speech related movements are processed; c) the amygdala and insula, where facial emotional expression is processed; d) fusiform face areas and superior temporal suculs, where attractiveness, gender and age are identified, and e) regions in prefrontal cortex and in the reward circuitry (as nucleus accumbens and orbitofrontal cortex), where the assessment of beauty is processed (Aharon et al, 2003; Briton et al, 2006; Brady, Campbel and Flaherty, 2004; Ishai, 2007; Ishai, Schimidt and Boesiger, 2005; Kircher et al, 2001; Singer et al, 2004). Quiroga et al (2005) has shown that specific neurons specialize for recognizing specific faces, a distinctive proof of the specificity of the face recognition neural circuits. These circuits enroll in deliberative and implicit social judgments.

Neuropsychological and functional neuroimaging investigations frequently use face expressions to probe brain regions involved in affect, highlighting regions such as amydgala, insula and 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, evaluations of personality, as well as employment prospects (Celerino et al, 2007; Ishay, 2007; Kranz and Ishai, 2006; Werheid, Schachat and Sommer, 2007). Functional Magnetic Resonance Imaging (fMRI) studies show that a complex network involving different brain regions (e.g., orbitofrontal cortex; medial prefrontal cortex; paracingulate cortices, insula, amydgala and superior temporal cortex) are involved in processing attractiveness (Ishai, 207; Kranz and Ishai, 206; Winston et al, 2007). More specifically, emotional circuits (e.g. orbitofrontal cortex, amygdale and insula) are involved with a role in sensing the value of social of attractiveness (Winston et al, 2007). The electroencephalogram (EEG) has also been used to study the temporal characteristics of appraising facial attractiveness. These studies have shown that face analysis involves distinct steps, with early events correlating with recognition of face physical characteristics and late components being associated with emotional, gender and social information carried by face expression (Cellerino et al, 2007; Werheid, Schacht and Sommer, 2007).

The EEG Brain Mapping of a Cosmetic Dermatology Treatment

Hialuronic acid (HA) was used in correcting nasolabial folds and in lips augmentation in 33 women aged 30 to 55 years old, with a mean age of 44. At the initial evaluation, patients were asked for demographic data and were inspected for nasolabial fold depth and lips volume loss. Informed consent was obtained from all patients before treatment investigation and the experimental protocol was approved by the Ethics Research Committee of the Catholic University of Campinas. Treatment consisted of injection of 1,0 ml of HA in each nasolabial fold, or the upper and lower lip. This was done under local anesthesia or infraorbital nerve blockage. Patients were reevaluated 48hs, 1, 2 and 3 months after the initial procedure. The reevaluation had the purpose of detecting side effects and assessing treatment durability.

THE EXPERIMENT

At the 3rd month evaluation, two networked personal computers were used for EEG recording and presenting the patient a questionnaire about:

1) *self-evaluation of face components* - hair; forehead; eyebrows; eyes; nose; chin; face contour; cheeks and neck, classified as superb; great; regular; bad and very bad.
2) *motivation for treatment* - selecting one or more options among**:** *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 them.

3) *self-evaluation of face appearance after the treatment* or *before and after photo comparison*– selecting one option among: *very much improved; improved; did not change; worsened or badly worsened.*
4) *treatment satisfaction* - comparing *before and after* photos and declaring herself *very satisfied; satisfied; none; unsatisfied; very unsatisfied*.
5) *family; friends and people at work evaluation of treatment results* - selecting one option among: *excellent; good; bad; very bad; no opinion*.
6) *decision to repeat the treatment* - selecting one option among: *definitely yes; yes; no; definitely no; undecided*.
7) *decision to recommend the treatment to other people* - selecting one option among: *definitely yes; yes; no; definitely no; undecided.*

Factorial and Regression analysis were used to disclose possible associations between answers to different items of the questionnaire.

The correlation entropy **$h(c_i)$** of the EEG activity (Rocha et al, 2004) recorded while answering the questionnaire was calculated for each electrode **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 to each questionnaire item and the associated **$h(c_i)$.** The values of the angular coefficients (□) for the calculated linear regression were color encoded to build the Regression EEG Mappings associated to each questionnaire item (see figure 2).

The poll data

Table 1 shows the frequency of face components patients classified as *superb or great* (questionnaire item 1). Eyes and hair were the preferred elements and forehead; eyebrows; nose and neck had the highest rate of disapproval. We recoded the face component evaluation according to the rule: S=5; G=4; R=3, B=2 and VB=1, and calculated a general appearance index for each patient as the mean of her evaluation of all face components. The mean general appearance index calculated for all patients was **4,07**. In other words, the majority of the patients consider themselves as attractive.

Table I – Face components evaluation: frequency of items classified as *superb* or *great*

	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**	**3O**	**26**	**4**	**3**	**0**	**4**	**0**	**4**	**11**	**0**

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

Patients decided about the treatment (questionnaire item 2) because they were already considering it (54%) and/or dissatisfied with their lips or nasolabial folding (52%). The fact that the treatment was free of charge just triggered the decision.

Patients were very *satisfied* or *satisfied* with the results of the treatment (questionnaire item 3), as well as with their facial attractiveness after the treatment (questionnaire item 4). No patient claimed to be *unsatisfied* with both the immediate and later treatment results. In addition, patients declared that family and friends made great comments about their new appearance (questionnaire item 5). As a result of all that, 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%).

The Brain Mappings

Regression Brain Mappings associated with the face component self-evaluation, treatment results and the self-evaluation of face appearance after the treatment (*Before and After* photo comparison) are shown in figure 2.

The **$h(c_i)$** calculated for the central (FZ, CZ and PZ – see figure 3 for the location of the 10/20 system electrodes) and right (FP2, T4 and P4) electrodes (green to blue electrodes in figure 2F) was positively correlated with *face component self-evaluation*, such that high **$h(c_i)$** at these electrodes were associated with a very positive self-evaluation (Max = 5 or superb). On the contrary, the **$h(c_i)$** calculated for the left (F3, F7, C3, P3 and T5) and right frontal (T5 and P4) electrodes (rose to dark red electrodes in figure 2F) was negatively correlated with *face component self-evaluation*, such that high **$h(c_i)$** at these electrodes were associated with a negative (Min = 3 or regular) self-evaluation.

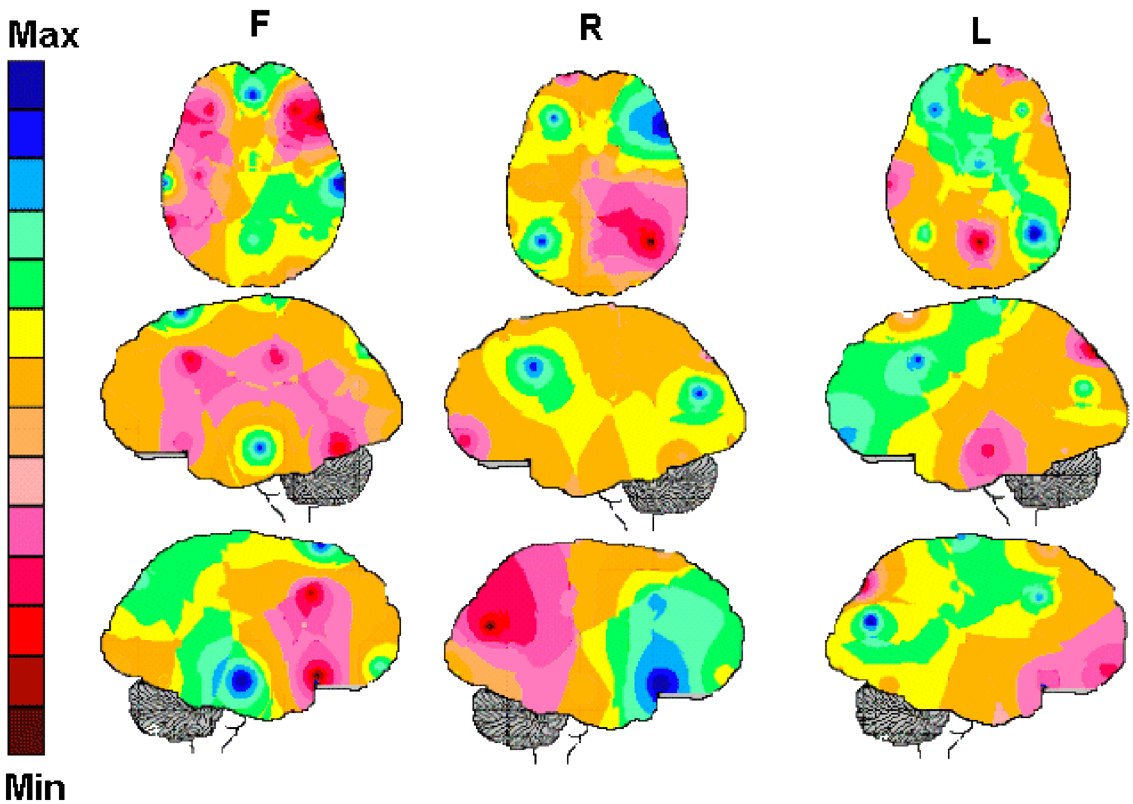

Figure 2 – Regression mappings $D = a + b_1 h(c_1) + ... + b_{20} h(c_{20})$ calculated for all volunteers such that negative values of b_i were color encoded from rose to dark red; positive values of b_i were color encoded from yellow to dark blue; and those $b_i = 0$ were color encoded as orange. The correlation entropy $h(c_i)$ calculated for the electrodes e_i^- associated to negative b_i contributes to make D →Min, while $h(c_i)$ calculated for the electrodes e_i^+ associated to positive b_i contributes D →Max. In the case of *face element component self-evaluation* (**F**): Max = 5 (or *Superb*) and Min= 3 (or *regular*); in the case of *attractiveness self-evaluation after the treatment* or *Before and After photo comparison* (**R**): Max = 5 (or very much improved) and Min= 4 (or improved), and in the case of *satisfaction with the treatment results* (**L**): Max = 5 (or *Satisfied*) and Min= 3 (or *none*).

Before and After photo comparison was positively associated with **h(c$_i$)** calculated with the F3, P3, F4 and F8 electrodes (green to blue electrodes in figure 2R), implying that high **h(c$_i$)** were associated with positive evaluation (Max = 5 or very much improved). On the contrary, the **h(c$_i$)** calculated for the electrodes FP1; P4, CZ, C4 and PZ were negatively associated (rose do dark red electrodes in figure 2R) with *the Before and After* classification (Min=4 or improved).

Finally, the self-evaluation of their appearance was positively related with **$h(c_i)$** calculated for the electrodes FP1, F3, F4, CZ, P3 and P4 (green to blue electrodes in figure 2L), such that high values of **$h(c_i)$ were** associated with a great appearance (Max = 5 or very satisfied). On the contrary, **$h(c_i)$** calculated for the electrodes FP2, T3, and PZ (rose to dark red electrodes in figure 2L), such that high values of **$h(c_i)$** were associated with a regular appearance (Min = 3 or none).

DISCUSSION

Beauty is very influential in human reproduction and socially motivated behaviors (Aharon et al, 2003). Beauty is more necessary for the woman than for the man. Also, women are judged more critically than men concerning aging, because modern urbanized societies allow only one standard of female beauty: 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 beauty is determined by the feeling she has about herself and opinions collected collected from her partner, family and friends.

Here, volunteers were satisfied or very satisfied with the components of their faces and EEG mappings showed that this evaluation is supported by a widespread set of neurons whose activity was recorded by a large number of electrodes (figure 3). The present results are in agreement with the literature showing that face recognition is supported by a specific and widespread neural circuit (Aharon et al, 2003; Briton et al, 2006; Brady, Campbel and Flaherty, 2004; Ishai, 2007; Ishai, Schimidt 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 those values obtained for the right posterior electrodes were directly correlated with a very positive classification of their face elements (figure 2F). The literature shows that the left hemisphere is more concerned with self body evaluation, and the right hemisphere is more concerned with the body people perception of other people (Alisson, Puce and McCarthy, 2001; Brady, Campbell and Flaherty, 2004; Ishai, Schmidt Boesiger, 2005; Kircher, 2001; Stone, and Valentine, 2005). Because female beauty is determined by the feelings she has about herself and socially collected opinions, it could be proposed that the left brain contributed to the self component and the right brain encoded the social component of the volunteers' evaluation of their beauty. If that is true, then the present results show that the self component contributed to reduce a more positive social evaluation of the volunteer's beauty. As a matter of fact, patients declared themselves dissatisfied with their appearance and motivated for the aesthetical treatment. Therefore, it may be concluded that aging creates a necessity to *remedy decaying beauty*, which in turn motivated the search for the aesthetical treatment.

The volunteers were asked to compare pre and post-treatment photos, deciding if their attractiveness was improved or worsened. They were unanimous in deciding that treatment improved or very much improved their appearance. The *very much improved* decision was backed up by the increase of **h(c_i)** calculated for the frontal (F8, F4, F3) and parietal (P3) electrodes (green to blue electrodes in figure 2R), whereas high values of **h(c_i)** at posterior electrodes (P4, C4, CZ and PZ) (rose to dark red electrodes in figure 2B) contributed to reduce the enthusiasm with the treatment results. The comparison of figures 2F and 2R shows a reversion of the correlation between **h(c_i)** for the left electrodes and attractiveness self-evaluation. Before the treatment, the left hemisphere contributed for a less positive decision about the attractiveness of the face element components, whereas high values of **h(c_i)** at the left electrodes F3 and P3 were associated with the *very much improved* decision after the treatment. The only difference concerned the right hemisphere is the reversion of the correlation between **h(c_i)** and decision making, such that the frontal electrodes became associated with the more positive evaluations (*very much improved*) and the posterior electrodes correlated more to the less positive (*improved*) evaluations after the treatment than before it. If the left hemisphere is more concerned with self-evaluation, then these results show that the volunteers were more positive about their appearance after rather than before the treatment, and the social evaluation was predominantly positive. Therefore, the analysis of the brain activity during these different decision makings seems to support the conclusion that "subjective" poll opinion is the result of complex neural processings involving neurons in widely distributed areas, evaluating both personal and social judgments of beauty.

The very positive overall evaluation of the treatment results (questionnaire item 4) was associated to high values of **h(c_i)** calculated for most of the left and right electrodes (see figure 2L). This may support the hypothesis that the positive evaluation of the results of treatment was due to both personal and social factors. That is in accordance with the fact that, after the treatment, the left hemisphere contributed more to a better positive appearance self-evaluation than before, and that volunteers referred to family and friends being very satisfied with their new appearance. Because patients were quite determined about repeating and promoting the treatment among family and friends, it may be concluded that their satisfaction with the results of the aesthetical intervention was translated into trust. The present result, therefore, seems to validate the proposed consumer decision-making model, correlating *necessity*, *motivation*, *satisfaction* and *trust*.

CONCLUSION

Neuromarketing was born in the 70s from the interest of marketing science in using neurosciences techniques to study and to understand the consumer's mind. EEG was the unique available non-invasive technique by that time and it provided some initial results. However, in those days neuroscience did not provide any model about decision-making to interpret these results. As a consequence, enthusiasm about this multidisciplinary approach decreased. fMRI studies on decision-making, in this beginning of the 21st century, are providing a better understanding of decision-making in different areas and about distinct subjects, having marketing is one of the target areas for such studies. Revived interest induced the present EEG study, considering that fMRI investigation requires the consumer's mind to be studied in special facilities and conditions imposing important restrictions over the research protocol, whereas our EEG mapping technology is portable and allowed us to study the patient satisfaction in the very same place she was aesthetically treated and medically evaluated. That EEG portability reduces the complexity of neuromarketing studies and makes this kind of research easily available to marketing professional.

The interested marketing professional may now design empirical studies to obtain a better understanding of consumer's necessities that create motivations for consumption of the product and services whose sales s/he is in charge of promoting. The understanding of the brain mechanisms correlating necessity and motivation is fundamental for developing products and services that fulfill consumer's necessities and generates the satisfaction that nurtures brand trusting. That knowledge is also necessary to better show clients how a given product or service may satisfy such needs. The understanding that neuromarketing may provide about consumer motivation to buy a good or service, certainly will increase the efficiency of the creative marketing professional in promoting his/her sales.

A word of caution is need, because neuromarketing is being subject of many ethical criticisms. Morality requires the marketing professional to use technologies such as the present one, to understand the relationship between necessity, motivation and products or services that promote satisfaction, instead of just trying to motivate consumption itself.

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Appendix – The EEG mapping technology

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

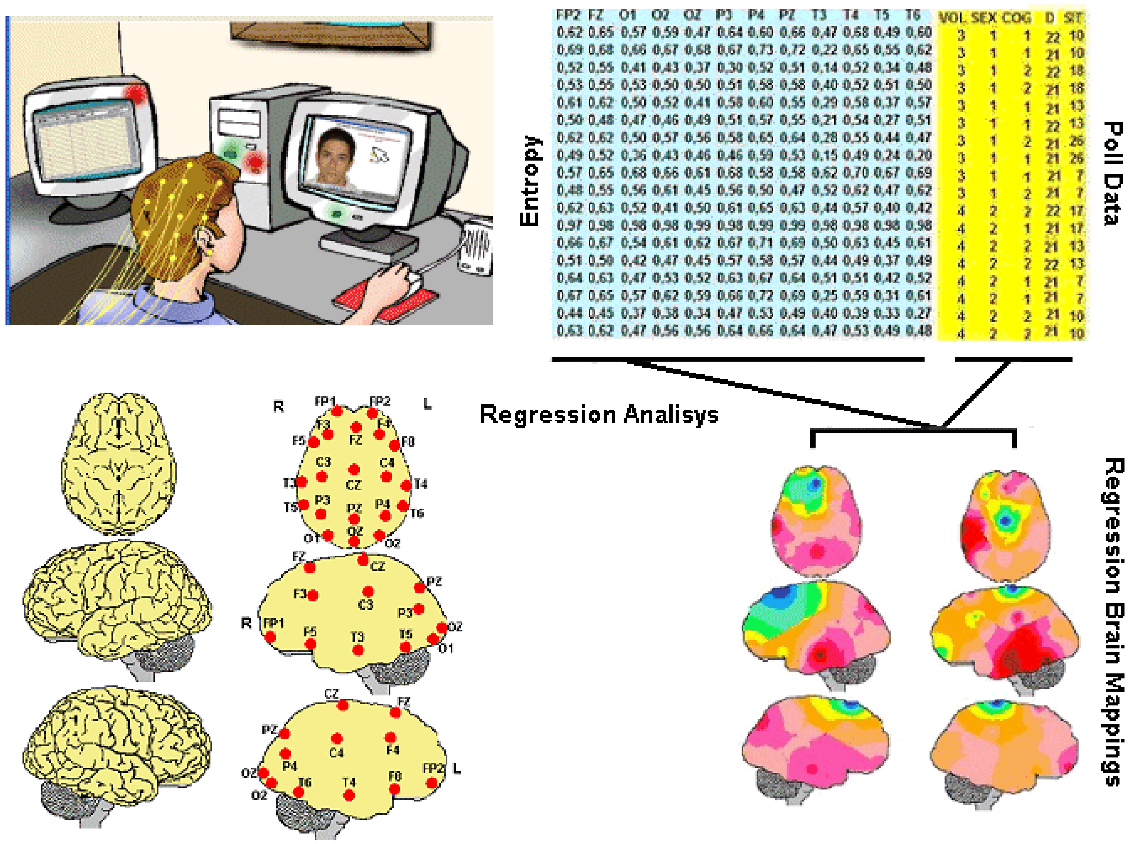
$$h(r_{i,j}) = -r_{i,j}\log_2 r_{i,j} - (1 - r_{i,j})\log_2(1 - r_{i,j}) \quad (1)$$

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

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

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

It may be stressed that there is no intention to assign any physiological meaning to the entropy $h(c_i)$. The correlation entropy $h(c_i)$ is assumed here to be a measure of the uncertainty about the existence or not of a correlation between the activity recorded by pairs of electrodes e_i, e_j. The entropy $h(r_{i,j}) = 1$ for $r_{i,j} = 0.5$ and $h(r_{i,j}) = 0$ for $r_{i,j} = 0$ or $r_{i,j} = 1$. Thus, $h(r_{i,j})$ measures how uncertain is the correlation between the EEG activity recorded by e_i, e_j. Entropy $h(\bar{r}_i)$ of the mean correlation **ŕi** provides another information about the covariance of the correlation between the activity recorded by e_i and all other e_j s. If $r_{i,j} = 0.5$ for all e_j s, then $\bar{r}_i = 0.5$ and $h(\bar{r}_i) = 1$. Also, If $r_{i,j} \to 0$ for some e_j s, $r_{i,j} \to 1$ for some other e_j s and $r_{i,j} \to 0.5$ for the remaining e_j s then $\bar{r}_i = 0.5$ and $h(\bar{r}_i) = 1$ . . However, $r_{i,j} \to 1$ ($r_{i,j} \to 0$) for most of the e_j s then $\bar{r}_i = 1$ ($\bar{r}_i = 0$) and $h(\bar{r}_i) = 0$. Finally, if $r_{i,j} \to 0$ for m electrodes e_j s, $r_{i,j} \to 1$ for n other electrodes e_j s and $r_{i,j} \to 0.5$ for remaining $19 + (M = n)$ electrodes e_j s then t_s. 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.



FP2	FZ	O1	O2	OZ	P3	P4	PZ	T3	T4	T5	T6	VOL	SEX	COG	D	ST
0,62	0,65	0,57	0,59	0,47	0,64	0,60	0,66	0,47	0,68	0,49	0,60	3	1	1	22	10
0,69	0,68	0,66	0,67	0,68	0,67	0,73	0,72	0,22	0,65	0,55	0,62	3	1	1	21	10
0,52	0,55	0,41	0,43	0,37	0,30	0,52	0,51	0,14	0,52	0,34	0,48	3	1	2	22	18
0,53	0,55	0,53	0,50	0,50	0,51	0,58	0,58	0,40	0,52	0,51	0,50	3	1	2	21	18
0,61	0,62	0,50	0,52	0,41	0,58	0,60	0,55	0,29	0,58	0,37	0,57	3	1	1	21	13
0,50	0,48	0,47	0,46	0,49	0,51	0,57	0,55	0,21	0,54	0,27	0,51	3	1	1	22	13
0,62	0,62	0,50	0,57	0,56	0,58	0,65	0,64	0,28	0,55	0,44	0,47	3	1	2	21	26
0,49	0,52	0,36	0,43	0,46	0,46	0,59	0,53	0,15	0,49	0,24	0,20	3	1	1	21	26
0,57	0,65	0,68	0,66	0,61	0,68	0,58	0,58	0,62	0,70	0,67	0,69	3	1	1	21	7
0,48	0,55	0,56	0,61	0,45	0,56	0,50	0,47	0,52	0,62	0,47	0,62	3	1	2	21	7
0,62	0,63	0,52	0,41	0,50	0,61	0,65	0,63	0,44	0,57	0,40	0,42	4	2	2	22	17
0,97	0,98	0,98	0,98	0,99	0,98	0,99	0,99	0,98	0,98	0,98	0,98	4	2	1	21	17
0,66	0,67	0,54	0,61	0,62	0,67	0,71	0,69	0,50	0,63	0,45	0,61	4	2	2	21	13
0,51	0,50	0,42	0,47	0,45	0,57	0,58	0,57	0,44	0,49	0,37	0,49	4	2	2	22	13
0,64	0,63	0,47	0,53	0,52	0,63	0,67	0,64	0,51	0,51	0,42	0,52	4	2	1	21	7
0,67	0,65	0,57	0,62	0,59	0,66	0,72	0,69	0,25	0,59	0,31	0,61	4	2	1	21	7
0,44	0,45	0,37	0,38	0,34	0,47	0,53	0,49	0,40	0,39	0,33	0,27	4	2	2	21	10
0,63	0,62	0,47	0,56	0,56	0,64	0,66	0,64	0,47	0,53	0,49	0,48	4	2	2	21	10

Figure 3– The experiment: Two networked microcomputers were used to record the EEG activity (10/20 system) while the volunteer was deciding about a questionnaire item. The beginning of the questionnaire item display and the moment a decision is made are saved in the database together with the type of decision-making (D) and time required (response time ST) to achieve such decision. The linear correlation coefficients $r_{i,j}$ for the recorded activity at each recording electrode e_i referred to the recorded activity for the other 19 recording sites e_j are calculated, for each questionnaire item and volunteer VOL. These $r_{i,j}$ are used to calculated the correlation entropy $h(r_i)$ for each recording electrode e_i . In this way, $h(r_i)$ is calculated for all 20 recoding electrodes. The corresponding values of $h(r_i)$ constitute the Entropy Data Base. Regression analysis between decision D about each questionnaire item and $h(r_i)$ is used to build the cognitive mapping. Each mapping shows the contribution $\beta_i\, h_m(r_i)$ of each electrode e_i the decision made D. $h_m(r_i)$ is the average of $h(r_i)$ calculated for all volunteers. The location of each 10/20 system electrode is displayed at the left brain drawings.

Linear regression analysis was used to study the correlation between $h(c_i)$ and response time $ST = t_s - t_q$ and logistic regression analysis was used to study the correlation between

$h(c_i)$ and P_2 (adequate) or $\bar{P}_2$ (not adequate) decision. The normalized values of $b_i h(c_i)$ were used to build the color encoded brain mappings to display the results of the regression analysis. The color encoding routine is commercial software. Statistically positive betas (p level < 0.5) are encoded from red (normalized $b_i h(c_i)$ tending to 1) to yellow (normalized $b_i h(c_i)$ tending to 0); statistically negative $b_i h(c_i)$ (p level < 0.5) are display from blue (normalized $b_i h(c_i)$ tending to -1) to green (normalized $b_i h(c_i)$ tending to 0); and statistically non-significant $b_i h(c_i)$ are shown in orange. Brain contours are used as references for spatial location of the 10/20 system electrodes.