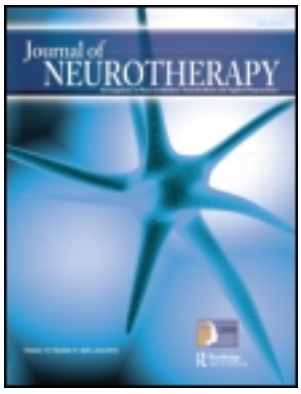

Journal of Neurotherapy: Investigations in Neuromodulation, Neurofeedback and Applied Neuroscience
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/wneu20

Evaluating Prefrontal Activation and Its Relationship with Cognitive and Emotional Processes by Means of Hemoencephalography (HEG)

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To cite this article: M. Serra-Sala, C. Timoneda-Gallart & F. Pérez-Álvarez (2012): Evaluating Prefrontal Activation and Its Relationship with Cognitive and Emotional Processes by Means of Hemoencephalography (HEG), Journal of Neurotherapy: Investigations in Neuromodulation, Neurofeedback and Applied Neuroscience, 16:3, 183-195

To link to this article: http://dx.doi.org/10.1080/10874208.2012.705754

Journal of Neurotherapy, 16:183–195, 2012

ISSN: 1087-4208 print/1530-017X online
DOI: 10.1080/10874208.2012.705754

Routledge
Taylor & Francis Group

EVALUATING PREFRONTAL ACTIVATION AND ITS RELATIONSHIP WITH COGNITIVE AND EMOTIONAL PROCESSES BY MEANS OF HEMOENCEPHALOGRAPHY (HEG)

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The main aim of this study is to determine the efficacy of the method of diagnosis known as hemoencephalography (HEG), which measures hemodynamic changes in the prefrontal cortex by determining differences in oxygen flow to show patterns of neuronal activity. Of the 5 tests designed for this purpose, 2 are strictly cognitive, while the other 3 have primarily emotional or sensitive content. The tests were applied to a sample of 70 university students. The Wilcoxon nonparametric signed rank test was applied to test the paired differences between the HEG baseline result and the HEG result of the task. Results show, first, that the HEG method successfully determines oxygen flow to the prefrontal cortex and clearly differentiates the subject's baseline from HEG activation during the task (Wilcoxon, $p < .05$); second, that HEG results vary depending on the type of activity, whether cognitive (low emotional load) or emotional (high emotional load) in such a way that cognitive areas, those located higher in the cortex (dorsolateral prefrontal), show less activity during emotional tests and more activity during cognitive tests, thus associating higher areas (dorsolateral prefrontal) with cognition and deeper areas (medial temporal, medial prefrontal, and cingulate) with emotion. The HEG procedure is effective in detecting states or situations of ailment or suffering not always accompanied by evident external manifestations. Furthermore, the procedure can differentiate between cognitive and emotional processing. The HEG method can help diagnosis in clinical settings due to its ability to detect painful-feeling processing independently of both body and verbal language.

INTRODUCTION

Researchers have long pursued the objective of determining the mechanism that produces specific human behavior in order to allow diagnosis and intervention in those situations involving dysfunctional behavior and the generation of conflict in relationships, unhappiness, and so forth. A multidisciplinary scientific approach is desirable (Hirshberg, Chiu, & Frazier, 2005; La Vaque et al., 2002).

It is evident that humans have the capacity to feel emotions just as we have the capacity to touch and feel physical pain, temperature, or pressure. It has been proposed that the sensitivity felt when neurons cognitively process any informative content is crucial, whether in ''normal'' or ''abnormal'' situations, as in the case of anxiety or depression (Power & Dalgleish, 1997).

If we consider the psychological approach based on the humanist-strategic model (Alabau-Bofill, 2003; Mayoral-Rodríguez, 2002; Pérez-Álvarez & Timoneda-Gallart, 2007a, 2007b; Timoneda & Pérez-Álvarez,

Received 5 December 2011; accepted 3 June 2012.
We thank Natàlia Adell-Calvet of the Unitat d'Assessorament Estadístic (University of Girona) for the statistical analysis. We are indebted to all participants for their invaluable assistance in the research presented here.
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1999), emotional processing explains defensive or protective behaviors in the face of a processed dangerous situation at neurological level. According to this theory, mental pain is processed as danger. The processing of danger is operating continuously in real life. Painful feeling processing happens constantly as a useful adaptation for survival. A common, unspecific processing of danger occurs in different uncountable situations linguistically expressed as stress, fear, anxiety, depression, anger, worry, and so on. The processing of mental pain (danger) takes priority over cognitive processing because where there is danger, survival is at stake, as posited by LeDoux in his research (LeDoux, 1996; LeDoux, Farb, & Ruggiero, 1990; LeDoux, Sakaguchi, Iwata, & Reis, 1986; LeDoux, Sakaguchi, & Reis, 1984).

The aforementioned premise implies two fundamental facts: first, that danger is processed by means of an unconscious neurological automatic mechanism and, second, that the conscious cognitive processing may be produced as an a posteriori result in the way of defensive or protective behavior if we are unconsciously processing danger (Alabau-Bofill, 2003; Damasio, 1970; Das, Kar, & Parrila, 1996; Mayoral-Rodríguez, 2002; Pérez-Álvarez & Timoneda-Gallart, 2000, 2007a, 2007b; Pérez-Álvarez, Timoneda-Gallart, & Reixach, 2006; Pujol et al., 2008; Timoneda-Gallart & Pérez-Álvarez, 1999). This assumption implies an unconscious processing precedes the a posteriori conscious cognitive processing. This has been corroborated by recent functional neuroimaging studies (Gazzaniga, 2007; Haggard & Libet, 2001; Libet, Gleason, Wright, & Paul, 1983; Soon, Brass, Heinze, & Haynes, 2008).

Neurological methods in the study of human behavior, in particular functional neuroimaging techniques (PET, fMRI, SPECT, MEG), have allowed us to establish some basic principles for the design of particular and concrete studies. Specifically, neuroimaging is a technique that allows exploration of the intact human brain while neuronal activity associated with specific mental processes takes place. Thus, the areas of the brain involved in mental functions are explored, and can also be related to any emotional and intellectual activity in the conscious subject (thoughts, emotions, reasoning processes, understanding, etc.). Furthermore, the high spatial resolution of fMRI, for instance, allows us areas of the brain to be located with high anatomical precision, which provides us with accurate information regarding where the brain process occurs.

Neuronal activity can be recorded by changes in the blood flow (hemodynamic changes) by using procedures different from functional neuroimaging as it is the hemoencephalography (HEG; Tinius, 2004; Toomim, 2002a; Toomim & Carmen, 1999; Toomim et al., 2004).

Two clearly differentiable neurological networks host two types of equally different processes, one cognitive, that is, the processing of information in the form of data in computational terms (Das et al., 1996), and the other emotional sensitivity. Both networks work with a clear anatomical and functional identity and in parallel, interacting with one another (Raichle & Snyder, 2007).

The cognitive network is exterior and dorsal, whereas emotional-sensitivity network is interior and ventral (Cabeza & Nyberg, 2000; Greicius, Krasnow, Reiss, & Menon, 2003; Minagawa-Kawai et al., 2009; Perez-Alvarez & Timoneda-Gallart, 2000, 2007a, 2007b; Perez-Alvarez et al., 2006; Pujol et al., 2008; Raichle & Snyder, 2007; Younger, Aron, Parke, Chatterjee, & Mackey, 2010). The interior and ventral structures are older, whereas the exterior and dorsal structures are younger on the scale of evolution. The interior and ventral network includes what we know as the limbic system. In recent years the interior and ventral network, the emotional sensitivity, has also become known as the ''default mode,'' to draw an analogy with telematic systems (Raichle & Snyder, 2007). That is, it is the predominant ''operating system'' in situations where the cognitive network disconnects or is inactive. Conscious activity is more characteristic of the cognitive network, whereas unconscious activity is more connected to the emotional-sensitivity network.

The last 10 to 15 years have witnessed the development of a technique known as HEG

(Carmen, 2004; Coben, 2006; Coben & Pudolsky, 2007; Legarda, McMahon, Othmer, & Othmer, 2011; Limsila, Toomim, & Kijvithee, 2004; Tinius, 2004; Toomim, 2002a, 2002b; Toomim & Carmen, 1999; Toomim et al., 2004; Zukiwski, 2011). HEG allows the measurement of hemodynamic changes, which are translated into changes in neuronal cellular activity. A correlation exists between blood flow activity in an area of the brain and the activity of the cells dependant on the blood, a phenomenon known as ''neurovascular coupling.'' The aforementioned procedure measures changes in the relationship between the variable absorption of infrared light and the nonvariable absorption of red light. The light penetrates down to the neurological tissue located under the external sensor and returns the light signal, the values being dependent on the perfusion and oxygenation of the underlying tissue (Toomim, 2002a, 2002b).

The sensor is positioned at the so-called Fpz point, which records activity at the anterior frontal pole, which is more dorsal exterior than ventral interior. The name Fpz is taken from the International 10–20 system of electrode placement (Rutten, 2009). In EEG recording, each electrode is awarded the initial of the lobe it is recording, F for frontal, T for temporal, P for parietal, O for occipital and C for central. The added ''z'' indicates that the sensor electrode is positioned on the imaginary middle line crossing the skull from front to back. Thus, Fpz will indicate the front position on the middle line, not to the right or left.

Having presented the fundamental background information, we now establish the hypothesis that HEG is capable of differentiating between states where cognitive processing is predominant from states where emotional-sensitivity processing is predominant. If this is indeed the case, HEG could represent a useful objective tool in the practice of psychological diagnosis and intervention, in so far as it could provide information for the diagnosis of personal behaviors or states, as well as the response to intervention. Given all of the preceding, this study has the following objectives:

- To verify the effectiveness of the HEG instrument in detecting differences in oxygen flow to the prefrontal cortex (Fpz), differentiating between the subject's ''resting state'' and state of activity.
- To establish whether differences exist in HEG results depending on the type of task the subject is involved in: cognitive or emotional.
- To verify whether these possible differences follow an activation pattern to increase or decrease basal activity according to the type of test the subject does.

METHODS

Subjects

The sample comprised 70 voluntary subjects (56 women, 14 men), all university students from the Faculty of Education and Psychology at the University of Girona. They were students of Educational Psychology ($n = 20$), the master's in Neuro-Educational-Psychology Diagnosis and Intervention ($n = 28$), the master's in Diversity Education ($n = 7$), and the master's in Teacher Training for Secondary and Upper Secondary Education, Professional Training and Language Teaching ($n = 15$).

Instrument

HEG is a technological mechanism that uses infrared light to measure oxygen flow through the skull. HEG technology uses the translucent property of the biological tissue. The biological tissue disseminates and conducts many types of radiant energy, and does so on a wide range of wavelengths. Specifically, nirHEG uses low-frequency red and infrared lights via light emitting diodes (LED optodes).

The light source and receptor (optode) are attached to a headband 3 cm apart. Both the electronic equipment and the headband were carefully designed and constructed to impede any possible entry of external light that might cause leakage and affect environmental light or distort measurements. It is important to highlight that, in contrast with the EEG method, low muscular tension or scarce subject

movements do not affect nirHEG measurements. Other possible sources of error were researched and were found to be minimal. Only around 5 to 10% of nirHEG readings come from the skull skin or tissue, because these regions of the body have little blood flow in comparison with brain tissue. Intense body movements might slightly increase cranial blood pressure, but the person administering the test can easily observe these movements and account for them.

The depth of effective penetration in the highly vascular cortical tissue is approximately 1.5 cm below the midpoint between the optodes. The entrance and exit light areas are 0.052 cm^2 at the skin surface. The light entrance and exit points and the refractive and scattering qualities of the tissue form a banana-shaped light field (Figure 1). The form of the optical path is discussed in research by Chance (1992) and Toomim and Carmen (1999).

The lights are emitted alternately onto the surface of the skin. The emitted light penetrates these tissues and is scattered, refracted, and reflected. A small amount of light modified by absorption of the tissue returns to the surface and is measured (Chance, 1992; Toomim & Carmen, 1999). The wavelength red light (660 nm) is absorbed less by the oxygenated hemoglobin than by the deoxygenated hemoglobin. The reference, the source of infrared light (850 nm), is affected relatively little by the degree of hemoglobin oxygenation.

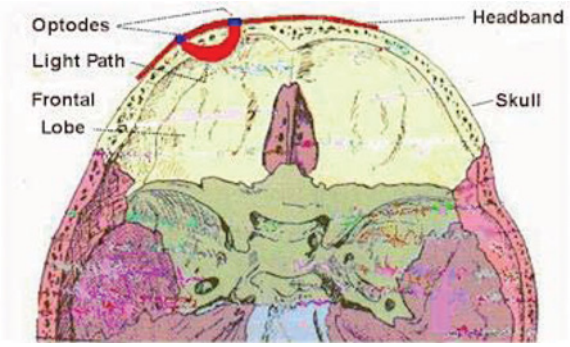

FIGURE 1. Illustration of the arc produced by light emitters in the hemoencephalography. From ''Intentional Increase of Cerebral Blood Oxygenation Using Hemoencephalography (HEG): An Efficient Brain Exercise Program,'' by H. Toomim, W. Mize, M. Yeekwong, M. Toomim, R. Marsh, & G. P. Kozlowski, 2004, *Journal of Neurotherapy, 8*, p. 7. (Color figure available online.)

Capillary oxygenation is barely affected by peripheral blood pressure and is mainly controlled by tissues' demand for energy. The concentration of oxygenated hemoglobin is therefore a useful measurement of local blood flow. Thus, mathematically, the formula for the HEG ratio would be as follows (Elwell & Hebden, 1999; Elwell, Springett, Hillman, & Delpy, 1999):

$$\text{nirHEG ratio} = \frac{\text{Red light (variable)}}{\text{Infrared light (affected little by oxygenation)}}$$

The nirHEG ratio or proportion of waves received in red with infrared light has a useful property. The numerator and denominator in the relationship are influenced in the same way by attenuation of the skin, the skull, and the length of the path. In this relationship, these variables are therefore rejected. The HEG ratio is the base of blood flow training. A standardized base for the HEG ratio was established by measuring Fp1 in adults, namely, 154 professionals from associations who attended meetings (Toomim et al., 2000). The standardized reference value was established at 100 ($SD = 20$) and used to calibrate all new spectrophotometers. Various recent studies have used the nirHEG system in combination with the EEG system for intervention, although many of these studies call for a controlled validation of the nirHEG system (Mize, 2004; Toomim, 2002a, 2002b; Toomim & Marsh, 1999; Toomim et al., 2004).

Figure 2 shows the all of the nirHEG equipment together. In addition to the HEG ratio, two further measurements are captured on the program screen, which are dependent on said ratio: the *segment index HEG gain*, or the percentage increase in the HEG ratio so far this session, that is, the session in progress, and the *current index HEG gain*, which is the immediate gain at any given moment and will logically vary constantly. We used the current index HEG gain for our evaluation studies, as this

FIGURE 2. HEG equipment used in this study.

indicates the time in seconds the subject maintains the same level of oxygenation or HEG ratio; furthermore, the collected values are shown in 1-s intervals, which is of great use for determining in more detail variability in oxygen flow depending on the task being carried out by the subject at a given time period.

Procedure

The researchers contacted subjects via the Department of Education and Psychology at the University of Girona. Once the aims of the project had been explained to them, their participation was requested. Those students who wished to participate in the study voluntarily were administered a questionnaire in order to homogenize the sample and exclude possible confusing factors. The following data were therefore recorded: age, gender, education, whether they regularly took any type of medication and if so which, and whether on the day they took the test they had taken any type of medication and/or smoked or consumed alcohol or drugs. In the event that any of these variables were observed it was decided that they would affect the results, so the subject data were not considered. In this study, there was only one such case in the entire sample.

The evaluation procedure consisted in administering five different tests (two cognitive and three with different degrees of emotional load), which lasted around 2 min each. All subjects carried out the tests in the same order while exposed to HEG.

Next we present the tests designed to fit the aims of the study.

FIGURE 3. Example of an item from Test 1 ''easy cognitive.''

Five tasks were designed to determine whether different HEG measurements exist depending on the cognitive or emotional nature of the task. Thus, in the first two, conscious cognitive activity was assumed to be high as subjects had to resolve a series of reasoning exercises as specified next. In the other three tests, the task had an evident emotional load attached to it, as described next.

In the first test (T1), which we call ''easy cognitive,'' different sets of two photographs of people or objects were presented to the participants on the computer. The task was to select the person who could run the fastest or the object that could reach a higher speed (e.g., an old man vs. a young healthy athlete.) Seven seconds were allowed per screen (Figure 3).

The second test (T2), which we call ''difficult cognitive,'' consisted in resolving different numerical exercises; in all items, subjects had to indicate the correct solution by choosing from three possible options, with a time limit of 7 s per screen (Figure 4).

In the third test (T3), subjects were presented with a moral dilemma with a high emotional load. The task consisted in reading a short story and then choosing whether to save the life of a family member who is seriously ill after an accident or of an unknown 5-year-old girl. They both urgently need a kidney transplant, but the hospital has only one organ.

The fourth test (T4) consisted of a metaphor that transmitted a message inviting

FIGURE 4. Example of an item from Test 2 ''difficult cognitive.''

subjects to reflect on how to live better and how to grow despite obstacles. In this case, the metaphor was divided into two parts. The first told of painful life experiences with which anyone could identify. In the second, subjects read general sentences about life that did not refer to concrete experiences.

In the final test (T5), different images were presented uninterruptedly one after the other at intervals of 6 s. The presentation contained three types of image: a first block of pictures of blood and violence (Subtest 1), a second showing smiling and happy faces (Subtest 2), and a third with photographs of severely malnourished people (Subtest 3).

The evaluation was conducted individually for each subject and in the presence of the same researcher working alone, in an isolated and duly conditioned room at the University of Girona. Cerebral activity was recorded at the Fpz point (Figure 5), as explained earlier. Before beginning each test, 30 s of baseline activity were recorded to establish oxygen flow maintained in the prefrontal cortex with the subject's mental activity at a minimum. To achieve this, subjects were asked to close their eyes and visualize the number 1, thereby unifying the base measurement for all subjects of the study. The tests then immediately appeared on the computer screen.

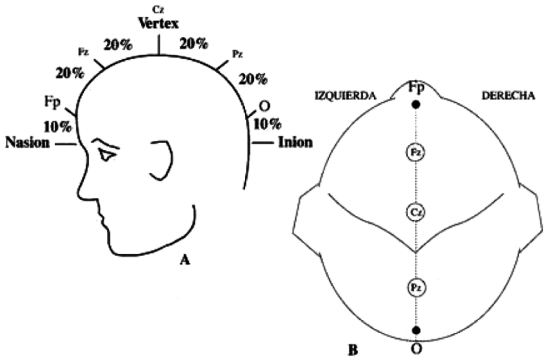

FIGURE 5. (A) Profile view. (B) View from above. *Note.* Fp = frontal polar point; O = occipital point.

Statistical Data Analysis

We checked normal distribution adjustment by the Shapiro-Wilk test. The distribution was non-normal, so the Wilcoxon nonparametric signed rank test was applied to test the paired differences between the HEG baseline result and the HEG result of the task. The differences between scores are rank ordered, and the significance test is based on ranks. The test applied was two-tailed; $p \leq .05$ was considered statistically significant. In a second step, those subjects that had been found to be significant in the Wilcoxon test were further analyzed in terms of descriptive analysis.

Ethical approval for the study was obtained.

RESULTS

As it appears in Table 1, 81.43% of the sample ($n = 70$) presented a significant difference

TABLE 1. Significant Difference[a] Between Hemoencephalography (HEG) Baseline and HEG Activity by Number of Tests

No. of tests	*n*	%
0	2	2.86
1	11	15.71
2	14	20.00
3	26	37.14
4	10	14.29
5	7	10.00

[a]Significant difference between HEG baseline and HEG activity during the test by the application of the nonparametric Wilcoxon.

TABLE 2. Distribution by Test for Number of Subjects with Significant Difference[a] Between Hemoencephalography (HEG) Baseline and HEG Activity

	HEG results			
	Nonsignificant		Significant	
Tests	n	%	n	%
T1	36	51.43	34	48.57
T2	28	40.00	42	60.00
T3	37	52.86	33	47.14
T4	30	42.86	40	57.14
T5	27	38.57	43	61.43

[a]Significant difference between HEG baseline and HEG activity during the test by the application of the nonparametric Wilcoxon.

(Wilcoxon, $p < .05$) between baseline and HEG activity in two or more of the tests according to our statistical analysis. Only two subjects in the sample showed no significant difference.

Table 2 shows the number of subjects for each test with significant or nonsignificant differences between baseline and HEG activity. The most relevant finding derives from Test 5 (T5), where 61.43% of the sample shows a statistically significant difference as opposed to the remaining 38.57%. Test 2 (T2) is statistically significant in 60.00% of the sample, and Test 4 (T4) in 57.14%. Tests T1 and T3 produced similar percentages of significant and nonsignificant results.

The second analysis focuses on the sample that showed statistically significant differences between baseline and HEG activity. Within this group, we separated the subjects who showed an increase in their HEG activity as compared to the baseline from those who showed a decrease. Concerning test T5, Table 3 shows that in 72.09% of subjects there was a decrease in HEG activity, whereas in only 27.91% of subjects there was an increase. Conversely, little difference is found between the two subgroups in T1, T2, and T3.

According to our conceptual framework, further analyses were necessary in T3 and T4. We divided the data obtained from T3 (dilemma) into two parts: HEG activity during the before-decision-interval and the after-decision-interval both from the baseline.

TABLE 3. Distribution by Test for Number of Subjects with Significant Difference[a] Between Hemoencephalography (HEG) Baseline and HEG Activity Who Show an Increase or Decrease in Activity

	Significant difference between HEG baseline and HEG activity			
	Decrease		Increase	
Tests	n	%	n	%
T1	18	52.94	16	47.06
T2	23	54.76	19	45.24
T3	19	57.58	14	42.42
T4	20	50.00	20	50.00
T5	31	72.09	12	27.91

[a]Significant difference between HEG baseline and HEG activity during the test by the application of the nonparametric Wilcoxon.

Table 4 shows that in the before-decision-interval HEG activity decreases in 60.90% of subjects and increases in the remaining 39.10%. In contrast, in the after-decision-interval the opposite results are obtained (30.40% decrease vs. 69.60% increase).

We also divided the results from T4 (metaphor) into two parts: HEG activity during the negative-experience-interval and the positive-experience-interval both from the baseline. Table 5 shows that in the negative-experience-interval HEG activity decreases in 62.30% of subjects and increases in the remaining 37.70%. Again, the result is inverted with similar percentages when the positive-experience-interval is analyzed (30.4% decrease vs. 69.6% increase).

TABLE 4. Distribution by Test for Number of Subjects with Significant Difference[a] Between Hemoencephalography (HEG) Baseline and HEG Activity Who Show Increased or Decreased Activity, According to the Stage of Test 3

	Significant difference between HEG baseline and HEG activity			
	Decrease		Increase	
Test 3	n	%	n	%
Interval before decision	28	60.90	18	39.10
Interval after decision	14	30.40	32	69.60

[a]Significant difference between HEG baseline and HEG activity during the test by the application of the nonparametric Wilcoxon.

TABLE 5. Distribution by Test for Number of Subjects with Significant Difference[a] in Activity Between Hemoencephalography (HEG) Baseline and HEG Activity Who Show Increased or Decreased Activity, According to the Stage of Test 4

	Significant difference between HEG baseline and HEG activity					
	Decrease		Increase			
Test 4	n	%	n	%	χ^2	*p*
Interval negative experiences	33	62.30	20	37.70		
Interval positive experiences	15	28.30	38	71.70	7.453	0006

[a]Significant difference between HEG baseline and HEG activity during the test by the application of the nonparametric Wilcoxon.

In the same line of analysis we focused our attention on T5, the one with the most significant initial results. This test was broken down into three subtests according to the nature of the pictures: violent and shocking images (Subtest 1), pleasant faces (Subtest 2), and undernourished people (Subtest 3). Table 6 Subtest 1 shows 68.50% of subjects with decreased HEG activity versus 31.50% of subjects with increased HEG activity, both as compared to the baseline. Subtests 2 and 3 produced more subjects whose HEG activity increased than subjects with decreased activity (57.40% vs. 42.60% and 55.60% vs. 44.40%, respectively).

TABLE 6. Distribution by Test for Number of Subjects with Significant Difference[a] in Activity Between HEG Baseline and HEG Activity Who Show Increased or Decreased Activity, According to the Stage of Test 5

	Significant difference between HEG baseline and HEG activity			
	Decrease		Increase	
Test 5	n	%	n	%
Block 1: bloody and shocking	37	68.50	17	31.50
Block 2: pleasant images	23	42.60	31	57.40
Block 3: undernourished people	44	44.40	30	55.60

[a]Significant difference between HEG baseline and HEG activity during the test by the application of the nonparametric Wilcoxon.

DISCUSSION

With regard to our first objective, we found that the HEG instrument does detect differences in oxygen flow in the prefrontal cortex (Fpz), differentiating between the baseline and HEG activity during each test (Table 1). The number of subjects with significant differences between baseline and HEG activity is more relevant in T5 (Table 2). We postulate that the result in T5 is related to the strong emotional load of the task.

On analyzing the sample with significant differences between baseline and HEG activity, the number of subjects with decreased activity is higher than those with increased activity in all tests apart from T4 (Table 3). Again, the result in T5 is compatible with what we have postulated earlier.

Analyzing the results from T3 (dilemma) and T4 (metaphor), decreased HEG activity appears during before-decision-interval of T3 (dilemma) and during negative-experience-interval in T4 (metaphor; Tables 4 and 5).

The before-decision-interval corresponds to the period when the decision is actually made, and therefore the corresponding mental processing has to be activated simultaneously. The before-decision-interval corresponds to a period when the subject is processing the content of the dilemma by reading on the computer screen. The after-decision-interval corresponds to a period when the subject verbalizes the decision. We understand the verbalization is an ''a posteriori'' time in mental processing, which is related with a different neurological network. On the other hand, the negative-experience-interval (Test 4) corresponds to the period when painful experience is felt by the subject as a shock, whereas the positive-experience-interval corresponds to the period when the painful experience is relieved.

Finally, the further analysis of T5 produced a clear decrease in HEG activity in Subtest 1, which was less pronounced in Subtest 3 (Table 6). We understand that the violent images shown in Subtest 1 had a more painful effect on the subjects, triggering an emotional

process that can explain the decreased effect on emotional neuronal network. Although both subtests (Subtests 1 and 3) give negative emotional input, the third subtest shows images to which the subject cannot directly relate (malnourished children), and therefore it causes a more conscious sadness and not unconscious emotional pain (feeling).

We postulate that all the previous statements on the results are consistent with the fact that decreased HEG activity translates into predominant emotional-sensitivity (painful feeling) processing (internal processing).

Four arguments need to be made to illustrate these statements in the light of our conceptual framework. The first argument is that we can differentiate two neurological networks, one responsible for cognitive processing and the other one responsible for emotional-sensitivity processing. The cognitive network is external and the emotional-sensitivity is internal. Second, the HEG detects the external network directly and the internal one indirectly. The third argument is the need to conceptualize both the emotional-sensitivity and painful feeling processing. Fourth, the procedure is applicable to clinical practice.

Regarding the first argument, evidence from multiple lines of fMRI investigation indicates that cognitive processing is supported by the younger external cortex, whereas emotional-sensitivity processing is supported by the older internal cortex. Dorsolateral prefrontal, parietal, occipital, and external temporal lobes are well known parts of the cognitive network. The amygdala, insula, cingulated cortex, and medial inferior ventral prefrontal cortex are parts of the emotional-sensitivity network. The core of this emotional network is the limbic system, and it is part of the reward and rest networks (default mode network). The default mode network refers to cortical areas that are active in the absence of goal-directed activity (Cabeza & Nyberg, 2000; Greicius et al., 2003; Perez-Alvarez & Timoneda-Gallart, 2000, 2007a, 2007b; Perez-Alvarez et al., 2006; Pujol et al., 2008; Raichle & Snyder, 2007). A large body of evidence indicates that any human behavior or experience involves the activation of two mental processes, the cognitive processing of information and the emotional processing of feelings, which are in constant parallel processing (Perez-Alvarez & Timoneda, 2000, 2007a, 2007b; Power & Dalgleish, 1997).

Second, according to the characteristics of the HEG sensor and where this sensor is placed (Fpz), the instrument captures external prefrontal activity, that is, cognitive activity. Assuming that both cognitive and feeling processing work simultaneously, and taking into account the nature of the information being processed, we can reasonably conclude that a decreased HEG activity largely corresponds with the processing of feeling.

Next we elaborate on the third point. We have attempted to develop an informed symbiosis of psychological theory and evidence from neuroscience (Alabau-Bofill, 2003; Mayoral-Rodríguez, 2002; Perez-Alvarez & Timoneda-Gallart, 2000, 2007a, 2007b; Timoneda-Gallart & Perez-Alvarez, 1999). Throughout the discussion, we are using ''emotional'' in the sense of emotional sensitivity, that is, the processing of feeling that can be dissociated from the processing of cognitive information. At the neurological level, this is not different from the dissociation between somatosensory processing (sensitivity processing) and motor processing. They are different processes that may often occur together. As a part of emotional-sensitivity processing, painful feeling processing happens constantly as a useful adaptation for survival. In fact, different fMRI studies testing symptoms such as stress, fear, anxiety, depression, and anger, identifies that a common unspecific processing of danger occurs and that the same brain areas are activated. This makes plausible the argument that there is a common neurological mechanism with different external emotional symptoms. Furthermore, research into human brain injuries has demonstrated that decision making depends on being able to anticipate the consequences of actions. However, this in turn depends on feeling processing and not on actual thoughtful deliberation. In other words, a lesion preventing someone from

feeling the consequences determines the unsuitability of decision making even if cognitive processing is intact. The decision-making process seems to depend on emotional rather than cognitive processing and is related to identity beliefs, which work more unconsciously than consciously (Damasio, 1970).

These findings are consistent with the fMRI evidence indicating that

> our brain might cheat when learning or behaving. Instead of trying to answer a question by reasoning, our brain explores a catalog of previous answers to similar questions. The brain builds a repertoire of rote responses to frequently encountered problems that it can use as appropriate. This cheating mechanism also exists in people suffering from amnesia. This mechanism is highly efficient whether it is about learning or non-learning. (Dobbins, Schnyer, Verfaellie, & Schacter, 2004, p. 316)

Other researchers have published in the same line of thought:

> The outcome of a decision can be encoded in brain activity of prefrontal and parietal cortex up to 10 second before it enters awareness. This delay presumably reflects the operation of a network of high-level control areas that begin to prepare an upcoming decision long before it enters awareness. (Soon et al., 2008, p. 543)

Others insist on it (Gazzaniga, 2007). Similar conclusions have been reached through methods other than fMRI (Haggard & Libet, 2001; Libet et al., 1983).

Consistent with other studies, fMRI evidence from our own research concluded that the anterior and posterior cingulated cortex and the medial ventral prefrontal cortex are associated with the emotional-dilemma condition as opposed to the nonemotional condition that is supported by cognitive external cortical areas. In other words, painful decision-making process, but not nonpainful decision-making process, activates the medial prefrontal cortex. Emotional dilemma fully implies the feeling-fearful processing, whereas the nonemotional condition does not (Perez-Alvarez et al., 2006; Pujol et al., 2008).

Outstanding evidence from animal experimentation demonstrated that painful-fearful sensitivity is unconsciously processed and controlled by the temporal amygdala, which sends unconscious, uncontrolled, and automatic protective-defensive responses. This process also involves the prefrontal cortex, which operates a posteriori.

The temporal amygdala, as soon as it encodes the signal, sends out activation instructions to whole body, the cardiovascular system, the respiratory system, and the muscles responsible for body language in the form of defense and protection. The most relevant finding of this research was that the amygdala also sends activation signals to the cognitive cortex, which is activated before receiving cognitive-informative news of the reason for the alarm. Later, when this information reaches the cognitive cortex, this cortex does not change its ongoing activity. Translating this into educational-psychological language we can extrapolate this as follows: When danger is experienced (subconsciously much more often than consciously), the temporal noncognitive amygdala sends out activation signals to the cognitive cortex as well as the somatic targets involved in the defense mechanisms. The cognitive cortex is activated, and it puts into action the cognitive information (thought). What is produced by the cognitive cortex in this situation is taken from experiences from the past or current ones taken in from the environment via the senses (precipitant factors). This cognitive action is an ''a posteriori'' time. This is why explanations may be considered justifications for the behavior that takes place. Likewise, we tend to explain what is happening to us by establishing cause–effect relationships with what are normally just precipitant causal factors generally linked to what entering through our senses in real time (LeDoux, 1996; LeDoux, Farb, & Ruggiero, 1990; LeDoux, Sakaguchi & Reis, 1984; LeDoux, Sakaguchi, Iwata & Reis, 1986; Pérez-Alvarez & Timoneda-Gallart, 2000, 2007a, 2007b).

Consequently, a rule of neurological operation can be deduced: The more the conscious processing is working, the more the external-dorsal cortex also works; conversely, the more unconscious the operation is, the more the inferior-interior structure works. Furthermore, we propose that the period before becoming aware of the decision is used by the brain to process beliefs at the unconscious level. Our study compares painful with a nonpainful decision making. We postulate that the deliberative thought associated with longer response times (T3 of our study) reflects the engagement of conscious abstract reasoning processes. This occurs after the processing of unconscious personal beliefs that is actually responsible for decision making. For example, after a child has solved a task, we can verify whether the verbally reported strategy is indeed the one in use, which can be deduced by observing the eye movements of the child. Likewise, personal beliefs work basically at a subconscious level beyond what we can see or hear externally between the input of information (dilemma presented) and the output of information (behavioral verbal or nonverbal response).

With the limitations of the study in mind, we can conclude that (a) the HEG is able to detect prefrontal activation; (b) the activation varies depending on the task, decreasing when negative emotional impact exists or increasing when it does not; (c) the HEG objectively detects emotional impact independently of what is verbally reported by the subject; (d) the HEG is able to detect the emotional process of decision making independently of what is verbally reported by the subject; (e) the decreased activity is consistent with body language (a reliable indicator of feeling), but not always with verbal language; (f) the HEG seems to be a useful tool to be used in clinical setting for both diagnosis and intervention. It is our hope that this study will generate an interest in performing larger scale studies.

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