

Can learning to read and write change the brain organization? An electrophysiological study

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It has been suggested that learning how to read and write during childhood influences the functional organization of the adult human brain. In the present study, cortical evoked potentials (ERPs) to a probe click stimulus were used to assess the extent of activation of the two cerebral hemispheres during a verbal memory task in literate and illiterate subjects. Left-hemisphere attenuation during the experimental condition was found in both groups. These findings suggest that for the illiterate subjects, left hemisphere predominantly mediates language processing. However, during the verbal memory task, significant intrahemispheric differences between groups were found at parieto-temporal areas. Results seem to indicate that learning how to read and write demands an intrahemispheric specialization with an important activation of parieto-temporal areas. These data support the view that the brains of illiterate subjects show patterns of activation that are different from those of literate subjects, thus reflecting that environmental conditions can influence brain organization.

Il fut suggéré que l'apprentissage de la lecture et de l'écriture durant l'enfance influence l'organisation fonctionnelle du cerveau humain adulte. Dans la présente étude, les potentiels évoqués corticaux (ERPs) en réponse à des déclics entendus par le participant furent utilisés pour évaluer l'étendue de l'activation des deux hémisphères cérébraux durant une tâche de mémorisation verbale chez des participants alphabétés et analphabètes. Une atténuation de l'hémisphère gauche durant la condition expérimentale fut trouvée chez les deux groupes. Ces résultats suggèrent que pour les participants analphabètes, l'hémisphère gauche gère principalement le traitement du langage. Cependant, durant la tâche de mémorisation verbale, des différences intra-hémisphériques significatives furent soulevées entre les groupes dans les zones pariéto-temporales. Les résultats semblent indiquer que l'apprentissage de la lecture et de l'écriture demande une spécialisation intra-hémisphérique avec une activation importante des zones pariéto-temporales. Ces données appuient l'idée que le cerveau des analphabètes montre des patrons d'activation qui sont différents de ceux des alphabétés, indiquant que les conditions environnementales peuvent influencer l'organisation cérébrale.

Se ha sugerido que aprender a leer y escribir durante la niñez influye en la organización funcional del cerebro humano adulto. En el presente estudio se usaron los potenciales relacionados a eventos (PRE) para evaluar la magnitud de activación de los dos hemisferios cerebrales durante una tarea de memoria verbal en sujetos alfabetos y analfabetos. En ambos grupos se encontró una atenuación significativa del hemisferio izquierdo durante la condición experimental. Estos resultados sugieren que tanto en los sujetos analfabetos como en los alfabetizados, el hemisferio izquierdo media el proceso del lenguaje. Sin embargo durante la tarea de memoria verbal, se encontraron diferencias significativas intrahemisféricas entre grupos en las áreas parieto-temporales. Los resultados sugieren que aprender a leer y escribir demanda una especialización intrahemisférica con una activación importante de áreas pariéto-temporales. Estos datos apoyan la visión de que el cerebro de los sujetos analfabetos muestra redes de activación que son diferentes que aquéllos sujetos instruidos, reflejando que condiciones medioambientales pueden influir en la organización del cerebro.

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In the study of brain-behaviour relationships, one of neuropsychology's most consistent and robust finding has been the lateralization of language functions to the left cerebral hemisphere in most humans, particularly right-handers (Geschwind & Levitsky, 1968; Luria, 1980).

The capacity for language has been associated with a predisposition for the left hemisphere to acquire speech and language. In Western cultures, a significant left-sided lesion will almost invariably result in impairments to most aspects of language, including written production and comprehension. Broadly defined speech areas in the left hemisphere have been identified and delineated, each of which is postulated to perform relatively specific functions. For example, a localized lesion in the posterior region of the left hemisphere near the angular gyrus in the adult brain may result in pure alexia, defined as the specific impairment of reading, while a lesion in the anterior region of the left hemisphere at the third frontal circumvolution will affect oral expression (Benson & Ardila, 1996).

However, as Kennepohl (1999) points out, there is accumulating evidence that left-sided dominance for language may be modified by identifiable environmental variables. For example, differences in language lateralization have been found in reading studies in Japan. Both phonetic (*kana*) and logographic (*kanji*) symbols are used in everyday written Japanese. Sasanuma (1975) reported that many aphasics with left-sided lesions exhibit a preserved ability to read *kanji* but not *kana* script. Tachistoscopic studies performed with neurologically intact individuals have produced left visual field (i.e., right hemisphere) advantages for *kanji* words (Elman, Takahashi, & Tohsaku, 1981). Thus, it is not only language but also how language is represented that influences the recruitment of the left or right hemisphere strategies.

Another line of studies has found that cultural factors, as reflected in orthographic systems, can also shape neurophysiological systems. Paulesu et al. (2000) showed that English-speaking subjects and Italian subjects used different areas of their brain while reading in their native languages. Thus, reading English or Italian words required different strategies, which means different patterns of neural involvement. Paulesu et al. pointed out that in English there are 1120 ways of representing 40 sounds (phonemes) by different letter combinations (graphemes). The mapping between graphemes, phonemes, and whole-word sounds are essentially ambiguous in the English

language; by contrast, in Italian, 33 graphemes are sufficient to represent the 25 phonemes of language, and the mappings from graphemes to phonemes are unequivocal. In order to find out how these differences affect brain activation patterns, the authors used positron emission tomography (PET) studies while their subjects read words and nonwords aloud, and found that Italians showed a greater activation in left superior temporal regions associated with phoneme processing, while English readers showed greater activation in left posterior inferior temporal gyrus and anterior frontal gyrus.

A third line of evidence on how environmental variables can alter brain organization comes from studies in illiterate populations. In a series of behavioural as well as neuroimaging studies, Castro-Caldas and Reis (2000) found that learning how to read and write during childhood influences the functional organization of the adult brain. In a series of behavioural studies, they found out that illiterates had difficulties repeating pseudowords, and in a brain activation study using PET (Castro-Caldas, Petersson, Stone-Elander, & Ingvar, 1998) they reported that the pattern of brain activation was very different for each educational group. According to these authors, learning the written form of language (orthography) interacts with the functions of oral language; thus learning how to read changes the way in which speech is processed.

Moreover, brain lesion data pertaining to illiterate subjects have revealed conflicting results. Lecours et al. (1988) studied the effects of unilateral stroke in large groups of either educated or illiterate Portuguese speakers. They reported that lesions in the right hemisphere resulted in a greater incidence of language difficulties in illiterate stroke victims than in their literate counterparts and that aphasia was less severe in left-sided stroke illiterate patients. However, other studies did not replicate these findings and found left-hemisphere dominance in illiterates (Damasio, Castro-Caldas, Grosso, & Ferro, 1976; Wechsler, 1976). Matute (1988) reported that although aphasia in illiterates was associated with left-hemisphere lesions, it was less severe and the distribution per aphasia type was different, that is, in the illiterate subjects Broca's type aphasia was more frequent, even with posterior lesions.

We can say that, up to date, right hemisphere language representation is less well known than the left hemisphere organization. The question remains as to whether the functional balance

between the two cerebral hemispheres while processing oral language could be modified by the knowledge of orthography; i.e., could literacy play a significant role in language lateralization?

Another way to address these questions is through the use of neurophysiological techniques such as the event-related potential (ERP). These techniques have provided the researcher with a complementary opportunity to understand more fully what is going on in the brain during the activation of different functional systems. Cognitive processes occur in a matter of milliseconds; up to two and a half correct decisions can be made per second and reaction time can be as fast as 150 milliseconds. Since ERP can measure neural activity occurring within a millisecond time range, it offers the possibility of revealing the sequence and timing of neural events occurring during the activation of specific cognitive tasks. ERPs are transient voltage fluctuations generated in the brain in conjunction with sensory, motor, or cognitive events. They are considered to represent the summation of electric fields of a large number of neurons activated in synchrony. The basic assumption when working with ERPs is that, as a result of an event, an ensemble of neurons functionally related to that event comes to exhibit a particular spatiotemporal organization; that is, patterns of coherent or coordinate synaptic events will occur in different areas of the brain in a temporal sequence determined by anatomical connections, transmission times, and similar parameters of the ensemble of neurons being stimulated (Harmony, 1984).

It has been found that there are at least two sensory systems involved in creating the electrical responses recorded at the scalp. These systems interact to form the various components of the ERP. One is a specific, direct projection to the primary sensory areas that evokes a short latency positive-negative wave complex; the other is a nonspecific or indirect system that primarily affects the later components. Sutton, Braren, Zubin, and John (1965) have reported that the early or specific components result from exogenous influences related to the character of the stimulus such as intensity, frequency, and patterning. These early components show marked cross-modality variations. The later nonspecific components are described as endogenous and vary according to the state of the subject, the meaning of the stimulus, and the information-processing demands of the task (Hillyard, Simpson, Woods, Van Voorhis, & Münle, 1984). The use of neurophysiological techniques such as ERPs

offer the possibility of identifying the spatial and temporal flow of information that takes place during the activation of different functional systems and might suggest ways in which this flow of information is altered during deficient cognitive processing.

Over the past few years, there has been a great deal of research on the relationship between the ERP and information processing in the brain. These studies have attempted to correlate ERP components with complex psychological variables such as selective attention (the N100 component), active discrimination of stimulus features (the N200), delivery of task-relevant information (the P300), and expectancy (the CNV). Although not as reliable as these four components, other endogenous brain potentials have been related to several levels of language processing such as phonetics (Molfese, 1978), semantics (Brown, Marsh, & Smith, 1976; Chapman, McCrary, Chapman, & Martin, 1980), and syntax (Kutas & Hillyard, 1982). Recently, ERPs have also been applied in the study of reading. A negative wave with a peak latency of 200–600 ms (N400) occurs when subjects notice semantically deviant words in sentences (Kutas & Hillyard, 1980a, 1980b, 1980c), read unpredictable words (Ostrosky, Canseco, Meneses, Próspero, & Ardila, 1987a; Ostrosky, Canseco, Meneses, Próspero, Ardila, & Zarabozo, 1987b), or name words (Stuss, Sarazin, Leech, & Picton, 1983).

Several studies have reported that ERPs, especially in the context of a probe paradigm, provide a reliable and noninvasive means of studying language lateralization both in normal subjects and in recovering aphasic patients. (Papanicolaou, Levin, & Eisenberg, 1984; Papanicolaou, Moore, Deutsch, Levin, & Eisenberg, 1988).

The probe-evoked potentials paradigm consists of recording ERPs to a repetitive probe stimulus (e.g., click or strobe flash) presented during a control condition when subjects attend to this stimulus exclusively, and during experimental conditions while, at the same time, subjects are engaged in language or other cognitive tasks. The dependent variable is the measure of the amplitude of the ERPs elicited to the probe stimulus exclusively during both control and experimental conditions.

In a series of studies, Papanicolaou et al. (1984, 1988) have reported that normal adults show greater left-hemisphere (LH) attenuation in their auditory probe ERPs when presented with language tasks and greater right-hemisphere (RH) attenuation during visuospatial tasks. The

degree of relative attenuation is interpreted as the degree of hemispheric engagement in the task.

The probe paradigm has also been used with adult aphasic subjects, revealing that aphasic adults who recovered language showed greater RH attenuation to language tasks than did dysarthric, RH damage, or normal subjects (Papanicolaou et al., 1988).

In the present study, we used an auditory probe ERP with literate and illiterate neurological intact subjects to study if the functional architecture of language is more bilaterally organized in either group.

METHODS

Participants

Fourteen neurological healthy subjects were tested. Seven subjects were illiterates who, for social reasons, had never attended school or had any notion of how to write even their own name, and nine subjects were literates, with more than 12 years of school attendance and with a regular habit of reading and writing. The mean age of subjects were 40.8 years ($SD=6.4$) and 41.2 years ($SD=6.2$), respectively. A neurological and psychiatric screening questionnaire was used to rule out previous neurological and psychiatric conditions such as brain injury, cerebrovascular disease, epilepsy, Parkinson's disease, psychiatric hospitalizations, etc.

Measurement

A handedness questionnaire was also presented; only right-handed subjects were included in the sample population.

In order to evaluate cognitive functioning, the NEUROPSI (Ostrosky, Ardila, & Rosselli, 1999) test was administered. This is a neuropsychological battery developed especially for Spanish-speaking subjects, standardized and validated according to age, from 16 to 85 years, and according to educational level, 0 to 24 years. Only subjects who scored within the normal range were included.

The criteria for inclusion in the illiterate sample were: (a) zero school attendance as a result of economical restrictions and/or long distances between home and school during childhood; (b) inability to write their own name; for this purpose, all the subjects were requested to write their names, and only those unable to do so were included in the illiterate sample; and (c)

normal performance in daily life activities (i.e., normal functional intelligence according to the subject's sociocultural environment); (d) right-handedness; and (e) normal neuropsychological profile.

Electrophysiological recording

Probe ERPs were recorded in the Neuropsychology and Psychophysiology Laboratory of the National University of Mexico. Electrophysiological data acquisition and analysis were carried out on a Neuroscan system. Scalp electrical activity was recorded from 32 monopolar derivations according to the 10–20 international system. An electrode cap (Electro-Cap International) was used. All electrodes were referenced to linked ear lobes and an additional EOG bipolar derivation was recorded with electrodes placed at the inner and outer canthi of the right eye. Electrode impedance was always below 5 kOhms. The signal was filtered between 0.1–30 Hz (3 dB down). Each trial comprised of 256 digitized EEG points (analogue to digital converter of 12-bit resolution) acquired at a sampling rate of 256 Hz, total epoch time 1 s. A pre-stimulus baseline of 100 ms was obtained in each trial and data acquisition continued 900 ms after stimulus onset. In addition, during the auditory tasks (control and experimental), the subjects fixated their gaze on a target point placed on the centre of the monitor screen to reduce the occurrence of significant contamination by eye movements. Each continuous recording was visually inspected to eliminate epochs contaminated with muscle activation, movement artifacts, and electrocardiographic signals. After that initial rejection, an individual blink rejection routine was applied to reject epochs contaminated with blinks exceeding peak-to-peak amplitude of +50 to -50 mv. Epochs on which one or more channels of the analogue to digital converter were saturated were also excluded (about 15% of trials were lost due to such artifacts). For every subject, averaged ERPs ($n=30$ trials) for each recording site were obtained for each stimulus condition (control and experimental) for both groups. These ERPs were submitted to a low pass-digital (zero phase distortion) filtering with an upper cut-off of 10 Hz. All data points were corrected (prior to plotting or measurement) by subtracting the average prestimulus amplitude value. In other words, all amplitude values were measured with respect to the average amplitude of the prestimulus value corresponding to each ERP. The

auditory probe stimulus was a 500-Hz click (10-ms ramp; 50-ms plateau) with an intensity of 70 dB and a rate of 1/s delivered binaurally through headphones. Subjects were asked to report any interaural loudness asymmetry; if present, minor adjustments (in 2-dB steps) were made until a subjective loudness match was found.

During the control condition, the task was simply to attend to the probe stimulus. In the experimental condition (verbal encoding), the participants were presented with a list of 30 low-imagery, high-frequency common nouns (i.e., love, liberty, happiness, peace) at a rate of approximately 0.5 words/s and were instructed to attempt to memorize the words. The list was repeated three times without interruption. In addition to the words, the probe stimulus was also presented over the headphones as before, but was irrelevant to the task (i.e., subjects were instructed to ignore the tones and concentrate on memorizing the words). To ensure compliance with the task subjects were tested immediately after presentation of the word list by a recognition test from a total of 50 words. Testing was accomplished in a single session ranging from 1 to 2 hours.

Statistical analysis

For the ERP measures, 11 electrode sites where the attenuation coefficient was largest were selected (Fz, Cz, Pz, Fc3, Cp3, T3, Tp7, Fc4, Cp4, T4, Tp8). For some analysis, homologous left and right electrodes were collapsed as anterior to posterior sites (frontal, central, parietal) and coronal sites (left, midline, right). Amplitude and latency measures were subjected to repeated measures ANOVA using group (illiterate and literate subjects) as the between-subject variable and anterior to posterior (frontal central, parietal) or coronal (left, midline, right) as within-subject variables.

RESULTS

No significant differences in the behavioural performance of the literate and illiterate subjects were found. On average, literate subjects recalled 26.7 out of 30 words and illiterate subjects 26.2 out of 30 words.

As to the relative hemispheric activation underlying such performances, the probe ERP data, reported below, also revealed basic similarities in the two groups. Auditory probe EP waveforms

recorded from the left and right areas were characterized by two major peaks, an early negative (N1) and a later positive one (P2), with average latencies of 101.5 (*SD* 29.4) and 210.0 (*SD* 30.0) ms, respectively. To assess relative hemispheric engagement during each task, the N1–P2 amplitude of the ERPs waveforms were used, following the procedure reported by Papnicolaou et al. (1988). The relative, task-specific attenuation of the probe response in each hemisphere was expressed as the ratio of the amplitude of the probe ERP obtained during processing divided by that obtained during the control condition. Thus, ratio values less than 1.0 indicate different amounts of task-specific probe response attenuation, and consequently different degrees of hemispheric engagement in the task, independently of variability in the raw ERPs.

Figure 1 presents the ERPs to clicks and to the words and how the attenuation coefficient was calculated. A ratio value of 1.0 reflects no amplitude changes across conditions whereas values below 1.0 indicate the degree of attenuation of the probe ERP in each hemisphere during the task.

To ensure that sensory probe ERPs, independently of their sensitivity to the cognitive task, were of comparable amplitude in the two groups and the two hemispheres, N1–P2 amplitudes of the ERPs obtained during the control condition were submitted to 2 (groups) by 2 (hemispheres) mixed design analysis of variance. As expected, both analyses resulted in null effects ($p > .05$), indicating that during the control condition the auditory ERPs were of comparable amplitude bilaterally, and did not differ between the literate and illiterate groups. Figure 2 illustrates the mean evoked potential (ERP) amplitude values for each hemisphere and group during the control condition.

Subsequently, to evaluate the relative degree of probe ERP attenuation in each hemisphere during the language task, amplitude ratio scores (task/control condition) of ERPs recorded in each hemisphere were computed. These ratio scores were submitted to two separate 2 (group) by 2 (hemispheres) mixed design analyses of variance. The analysis of the experimental data resulted in a significant main effect of hemispheres, $F(1, 14) = 14.19$, $p = .002$, and no significant group or interaction effects ($p > .05$). These data indicate that, in both groups, engagement in the verbal memory task resulted in a significantly greater left hemisphere attenuation, suggesting that the left hemisphere predominantly mediates the linguistic

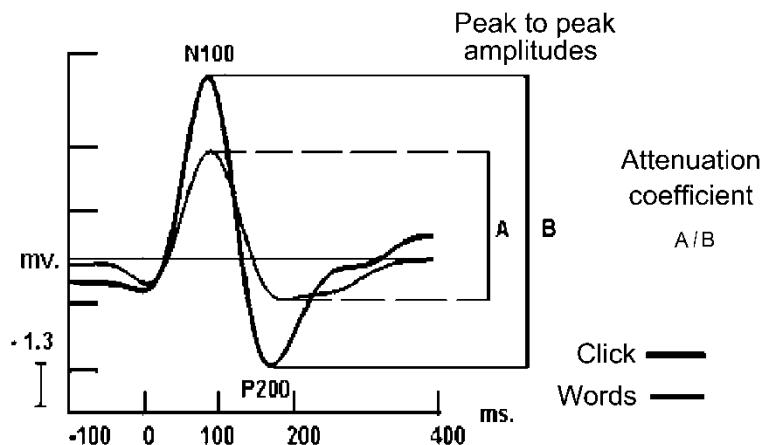


Figure 1. Peak to peak amplitudes of ERPs to clicks and to words and the formula for obtaining the attenuation coefficient. The relative, task-specific attenuation of the probe response in each hemisphere was expressed as the ratio of the amplitude of the probe EP obtained during processing (verbal memory) over that obtained during the control condition (clicks). Thus, ratio values less than 1.00 indicate different amounts of task-specific probe response attenuation, and consequently different degrees of hemispheric engagement in the task, independently of variability in the raw ERPs. A ratio value of 1.0 reflects no amplitude changes across conditions whereas value below 1.0 indicates the degree of attenuation of the probe ERPs in each hemisphere during the task.

operations required by this task for both literate and illiterate subjects. Figure 3 illustrates the mean evoked potential (ERP) amplitude ratio scores for each hemisphere and group during the verbal memory task.

To further evaluate if there were differences within hemispheres, ratio scores were submitted to a 2 (group) by 5 (sites: frontal, fronto-temporal, temporo-central, and parieto-temporal) mixed designed analysis of variance. Separate analysis was carried out for the left and right hemispheres. In both hemispheres, a significant

interaction between group and site was found, $F(4, 56)=3.38, p=.01$. A posteriori analysis revealed significant differences between groups only in parieto-temporal areas ($p<.05$). These data indicate that, in the illiterate group, engagement in the verbal memory task resulted in significantly less activation of parieto-temporal areas. Figure 4 illustrates the mean ERP amplitude ratio scores for frontal, fronto-temporal, temporo-central, and parieto-temporal sites. Solid lines indicate literates and broken lines, illiterates.

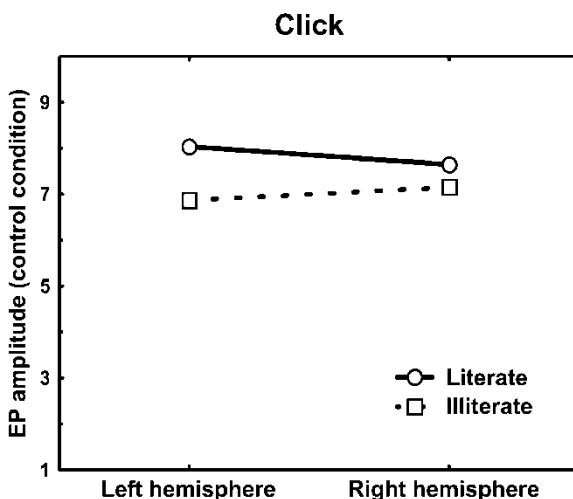


Figure 2. Mean ERP amplitude values for each hemisphere and group during the control condition. During this condition the auditory ERPs were of comparable amplitude bilaterally, and did not differ between the literate and illiterate groups. Solid lines with circles indicate literates and broken lines with squares indicate illiterates.

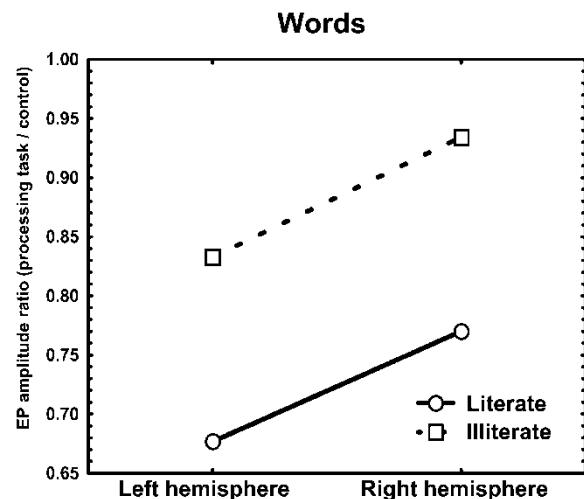


Figure 3. Mean evoked potential (EP) amplitude ratio scores for each hemisphere and group during the verbal memory task. Solid lines indicate literates and broken lines indicate illiterates. As can be appreciated in both groups, engagement in the verbal memory task resulted in significantly greater left hemisphere attenuation.

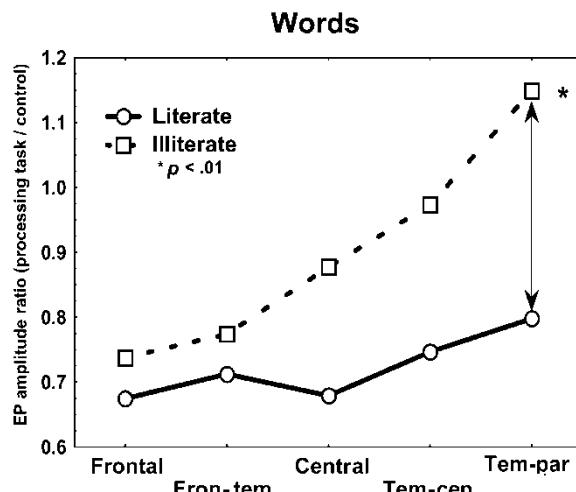


Figure 4. Mean ERP amplitude ratio scores for frontal, fronto-temporal, temporo-central, and parieto-temporal sites. Solid lines with circles indicate literates and broken lines with squares indicate illiterates. Significant differences between groups were found in parieto-temporal areas ($p < .05$).

DISCUSSION

The present probe ERPs data demonstrated that during the control condition the auditory ERPs were of comparable amplitude bilaterally, and did not differ between the literate and illiterate subjects. On the other hand, left hemisphere attenuation during the experimental condition was similar in both groups. These findings suggest that for the illiterate subjects, left hemisphere predominantly mediates language processing. However, during the verbal memory task, significant intrahemispheric differences between groups were found in parieto-temporal areas. The literate group shows a very similar attenuation across the five areas whereas the illiterate subjects did not show attenuation in this specific area. These data seem to indicate that learning how to read and write demand an intrahemispheric specialization with an important activation of parieto-temporal areas. These brain regions have been associated with object and word naming and semantic processing in several studies (Paulesu et al., 2000; Price, Moore, Humphreys, Frackowiak, & Friston, 1996; Vandenberghe, Price, Wise, Josephs, & Frackowiak, 1996). Thus it seems that learning how to read and write not only changes the areas involved during reading but also the ones recruited during verbal memory. It is important to point out that the differences between groups were not due to abnormalities in these areas since all of our illiterate subjects had an intact neuropsychological profile and intact functional skills, and their

illiteracy was due to social reasons. Furthermore, no significant differences in the behavioural performance of the literate and illiterate subjects were found.

As suggested by Castro-Caldas et al. (1998), learning to read and write adds a visuographic dimension, based on operation of matching phonemes and graphemes, to the internal representational system for spoken language, so learning a specific skill during childhood may partially determine the functional organization of the adult brain.

Our results are also in accordance with other neuroimaging studies, such as that reported by Paulesu et al. (2000) in English and Italian word reading and Castro-Caldas et al. (1998) in illiterate subjects, since both studies reported different brain activation patterns associated with cultural factors.

In conclusion, our electrophysiological data supports the notion that cultural factors, as reflected by learning how to read, can powerfully shape adult neuropsychological systems.

Illiteracy still represents a significant social phenomenon. Currently, about 876 million people are illiterate (UNESCO, 2001). In human history, writing only dates back some 5000 to 6000 years, and just a few centuries ago, reading and writing abilities were uncommon among the general population. It might be assumed that the acquisition of reading and writing skills has changed the brain organization of cognitive activity in general. Very important cognitive consequences of learning to read and to write have been suggested, not only in language but also in visual perception, logical reasoning, remembering strategies, and formal operational thinking (Ardila, Rosselli, & Rosas, 1989; Castro-Caldas & Reis, 2000; Manly et al., 1999; Ostrosky-Solís, Ardila, Rosselli, López, & Mendoza, 1988; Ostrosky-Solís, López, & Ardila, 2000). The analysis of illiteracy can help, in consequence, not only to discern the influence of educational background on cognitive performance, but also to contribute to a better understanding of the cerebral organization for cognitive activities.

Undoubtedly, as Castro-Caldas and Reis point out (2000), the brain can be understood as an organ that adapts to several types of internal and external influences. The interaction of these complex concurrent stimuli through life shapes the highly differentiated biological arrangement of the brain and its consequent physiology. Thus, the analysis of illiteracy performances on cognitive tasks can significantly increase the understanding

about brain organization of cognition under normal and abnormal conditions.

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