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NORMAL AND ABNORMAL READING PROCESSES IN CHILDREN

Neuropsychophysiological Studies

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Abstract

Early identification of dyslexia would be fundamental to prevent the negative consequences of delayed treatment in the social, psychological and occupational domains.

Movement-related potentials of dyslexic children are characterized by inadequate ability to program movements and reduced capacity to evaluate their performance and to correct their errors.

Reading-related potentials recorded during different reading conditions elicit a series of positive and negative components with specific functional meaning and with a characteristic spatial-temporal pattern. These reading-related potentials, when analyzed with sLORETA, show significantly different patterns of activation when comparing self-paced reading aloud to passive viewing of single letters.

Comparison of fMRI and sLORETA during both tasks showed that the cortical region with the widest inter-modality similarities is the middle-superior temporal lobe during self-paced reading aloud.

Neuropsychological studies have shown the existence of clinical subtypes of dyslexia; these studies have been confirmed by the results of ICA applied to the EEG.

Dyslexia can be defined as a disorder of programming and integrating ideokinetic elements, associated with a deficiency in the fast processing and integration of sensory information, with reduced efficiency of error systems analysis. Each of these phenomena occurs at different levels of the central nervous system and at different times.

Introduction

Developmental dyslexia is a neuropsychological disorder that affects reading and writing skills: subjects who are affected generally have intelligence within normal limits, normal hearing and visual acuity and have received adequate education. At the social, psychological and occupational level, dyslexia has a significant impact. In general, the level of education of dyslexic individuals is less than what they could potentially reach on the basis of their intellectual ability, with significant side effects on their emotional and relational abilities.

The efficacy of a therapy is greater the earlier it is done. For this reason it is important to identify the presence of disorders of reading beginning with the first grade of primary school; moreover it is important to design rehabilitation treatments based on a precise knowledge of the clinical

manifestations of dyslexia. The most obvious symptoms of the presence of dyslexia are lack of reading fluency and reading/writing errors.

Neuropsychology of Dyslexia

Several methods have been used to diagnose dyslexia. For many years the most widely used method has been diagnosis based on exclusion criteria. This method, while providing objective criteria for a correct diagnosis, does not allow the identification of clinical subtypes of dyslexia. In an attempt to overcome the limitations of diagnosis by exclusion, many researchers have attempted to identify the psychological processes underlying learning disabilities through a diagnostic approach termed “indirect” (Boder, 1973) or “extrinsic” (Ellis, 1985). This approach relies on eliciting the typical neurological or psychometric and psycholinguistic concomitants. Though useful, this approach is insufficient in itself for the diagnosis, since most of the concomitants can also exist without developmental dyslexia.

An important feature of dyslexia is the reduced ability to carry out a phonological analysis of individual words. This difficulty is indicative of an altered auditory perception and memory. A dyslexic child may guess a word from minimal clues, for example from the first or last letter and the length of a word. He also tends to read words better in context, although he may substitute a word similar in meaning but dissimilar phonetically. Omission or substitutions of different syllables while reading multisyllabic words are also very frequent. This is referred to as a “gestalt” or “global” approach to reading. A further important aspect of reading deficits associated with dyslexia concerns a weak perception and lack of visual memory; the child thus has difficulty learning what the letters look like. This difficulty is reflected in misplacements of accents and confusion of reversible letters and mirror reading and writing. Therefore Myklebust (1968) confirmed the existence of a visual and an auditory dyslexia, and Kinsbourne and Warrington (1963) have outlined two syndromes, “language retardation group” and “Gerstman group.” Bakker (1992) has described “Language type” and “Perceptual type” dyslexia.

Dyslexia can, therefore, manifest as a wide and varied spectrum of errors. Empirical demonstrations have shown that dyslexia is not a homogeneous syndrome, but comprises different subtypes, each one with its own characteristics and features (Castles & Coltheart, 1992).

Dyslexia Subtypes

Boder (1973), inspired by the studies of Bannatyne (1966), Benton (1962), Birch and Belmont (1964) and Myklebust (1968), and observing the variety of reading errors of dyslexic subjects, introduced a “direct” diagnostic approach that involved the observation of the performance observed in the course of reading and writing to differentiate subtypes of dyslexia (Boder, 1968). The operating assumptions were as follows:

- 1) Reading requires visual perception and discrimination, visual sequential memory and recall, and directional orientation (Benton, 1962; Birch, 1962). It also requires cross-modal integration, including the translation of visual symbols into meaningful auditory equivalents (Birch & Belmont, 1964). Writing requires, in addition, fine motor and visuo-motor coordination and tactile-kinesthetic memory.
- 2) Reading and writing are viewed as two interdependent functions and therefore must be analyzed “jointly.”
- 3) A normal reader recognizes the familiar words that constitute his or her sight vocabulary through the visual channel as instantaneous visual gestalts of whole words, without having to discriminate individual letters or component syllables. He or she reads familiar words on sight or “visualizes”

them (Myklebust, 1965). In contrast, a normal reader reads unfamiliar words through the auditory channel by a process of phonetic analysis and synthesis.

- 4) In the dyslexic child, normal reading is dissociated (Boder, 1971). The normal automatic interplay of gestalt and analytic-synthetic processes is disrupted. The dyslexic child reads and spells differently from the normal reader both qualitatively and quantitatively.

On the basis of these assumptions, Boder (1973) has postulated the existence of three subtypes of dyslexia: dysphonetic, dyseidetic and mixed. These have been also found in the Italian language by applying the Direct Test of Reading and Writing (TDLS), the translated version of the Boder test to the Italian language (Bindelli et al., 2001; Chiarenza, Barzi, Coati & Cucci, 1992; Chiarenza & Bindelli, 2001; Chiarenza & Cucci, 1989; Chiarenza, Cucci & Coati, 1990; Chiarenza et al., 2004). Readers with dysphonetic dyslexia show good skills in visual-gestalt function and disability in auditory function analysis. They have difficulty in making the phoneme-grapheme association and consequently do not develop phonetic skills to decode if not re-educated. Readers with dyseidetic dyslexia show good skills in analytic-synthetic auditory function and difficulties in the visual-gestalt function. They show a deficit in visual memory and perception of letters and whole words with important negative consequences in the development of an adequate internal vocabulary. Readers with mixed dyslexia have a global deficit, even in difficulties in the organization of visual and auditory perception. These difficulties prevent the formation of an internal vocabulary and the acquisition of phonetic skills. The words that can be recognized on sight and written properly are just those of the first school level or very simple words.

In summary, we can say that reading and writing are two interdependent functions and must be analyzed "jointly." It follows that the integrity and the automatic integration of auditory, visual and kinesthetic-motor processes are essential prerequisites for fluent reading and writing.

Another clinical aspect of dyslexia that has been little explored is the lack of fluency and prosody during reading, namely aspects related to the organization of movement. Various difficulties in the execution of neuromotor acts, such as simple repetitive movements or alternating complex movements such as bimanual coordination have long been observed in dyslexic children (Abercrombie, Lindon & Tyson, 1964; Bruininks & Bruininks, 1977; Connolly & Stratton, 1968; Denhoff, Siqueland, Konich & Hainsworth, 1968; Fog & Fog, 1963; Klicpera, Wolff & Drake, 1981; Lewis, Bell & Anderson, 1970; Pyfer & Carlson, 1972). Furthermore, clinical signs such as dysrhythmia and the presence of synkinetic movements have often been described in dyslexic individuals (Adams, Kocsis & Estes, 1974; Denckla, 1973; Kennard, 1960; Rutter, Graham & Birch, 1966; Stine, Saratsiotis & Mosser, 1975; Wolff & Hurwitz, 1973). These difficulties were interpreted as a disorder of the temporal organization of motor skills (Denckla, 1973; Klicpera et al., 1981). These observations were also recently confirmed by Punt, Jong, Groot and Hadders-Algra (2010), who reported that 87% of dyslexics exhibit minor neurological dysfunction, especially in fine manipulative skills, the regulation of muscle tone and the excessive presence of associated movements. All of these observations support the hypothesis of an important involvement of cerebellar function in reading and writing. It is therefore possible to maintain that we are facing a considerable heterogeneity in the dysfunction of skills in dyslexic children, not only visual and auditory, but also motor: Nicolson and Fawcett (2005) stated that children with dyslexia show difficulties when they have to acquire new skills quickly and fluently, and when they have to assemble two or more actions.

In our opinion, the reason for the neglect of the motor component of dyslexia lies in the fact that all experimental designs, both neurophysiological and behavioral, were built on the stimulus-response model. This is able to describe *only* phenomena that occur in the interval between the stimulus and the response of the subject, without being able to observe the phenomena before the onset of the stimulus and after the onset of the response. In this way, only phenomena related to the processing of auditory and visual stimuli have been described.

To study in detail the organization of a motor act, both simple and complex, such as reading and writing, it is necessary to devise other experimental models that take into account not only what happens during the processing of a stimulus, but also phenomena that take place before and after it. This is the fundamental and unique contribution of cognitive psychophysiology.

Psychophysiology of Dyslexia

Belmont (1980) reported that reading and writing are processes that require high skills and complexity that comprise a set of serially and hierarchically organized modular routines. Children who develop a reading disorder are lacking in the control of perceptual and motor behaviors (Belmont, 1980). Therefore, the performance of a complex perceptual-motor task appears to be particularly well suited to provide information on those systems and subsystems that regulate and organize the functions of reading and writing (Chiarenza, Papakostopoulos, Guareschi Cazzullo, Giordana & Giammari Aldè, 1982a). In addition, since the assumptions in dyslexia predict poor reading skills, a test of perceptual-motor skills, which lies outside the domain of reading, would be particularly suitable to test this hypothesis.

The task we used was self-paced, voluntary, goal-directed and interactive. To perform adequately, it requires the following skills: bimanual coordination, bimanual ballistic movements, adaptive programming, learning a proper timing and performance improvement. The task provides online knowledge of results and feedback (Chiarenza et al., 1982a, 1982b). In particular, the subject sat in an armchair 70 cm in front of an oscilloscope and held a joystick-type push button in each hand. The excursion of the button was 5 mm. The task consisted in starting the sweep of the oscilloscope trace with the left thumb and stopping it in a predetermined area of the oscilloscope by pushing the other button with the right thumb. The sweep velocity was 1 mm per ms and the target area corresponded to a time interval between 40 and 60 ms. The brain electrical activity associated with this task is called movement-related brain potentials. Using this task, we have shown that dyslexic children, besides being slow and not very accurate from a behavioral point of view, present a deficit of programming movements, a deficit of visual and kinesthetic sensory processes and a deficit and a reduced capacity to evaluate their performance and correct their errors (Chiarenza, 1990; Chiarenza et al., 1986; Chiarenza et al., 1982a, 1982b).

Dyslexic subjects showed a reduced BP amplitude of very short duration, indicating a non-adequate preparation; MCP reduced amplitude, indicating a lack of kinesthetic processing; N100 and reduced P200 amplitude, indicating a deficit of visual perception and reafferent activity, respectively; and SPP reduced amplitude on the parietal regions and the presence of PAN on the central and frontal regions, suggesting a reduced ability to evaluate target performance and non-target performance, respectively (for more details see Chiarenza, 1990).

These studies clearly demonstrate that dyslexia is not only a phonological or a gestalt deficit, but also a praxic disorder in which praxic abilities, such as motor programming, sequential and sensory-motor integration and evaluation processes, are required and somehow defective in dyslexia.

Subsequently, Chiarenza, Olgiati, Trevisan, Marchi and Casarotto (2013), by recording the electrical activity of the brain associated with reading aloud letters visually presented for 5 ms, described the specific brain responses related to this event, called reading-related potentials (RRPs). The recording of these potentials has been extremely helpful in understanding the dynamics of the activation of cortical areas involved in reading.

In designing a research protocol of this type, we must take into account the fact that reading is a voluntary and conscious process that needs specific attention mechanisms. To investigate the interactions among these processes, it is appropriate to give the subject the possibility to indicate, for example by pressing a button, when starting to read. It is also necessary to record, in addition to the potential of the brain, the activity of thumb muscles associated with button presses and lip muscles associated with

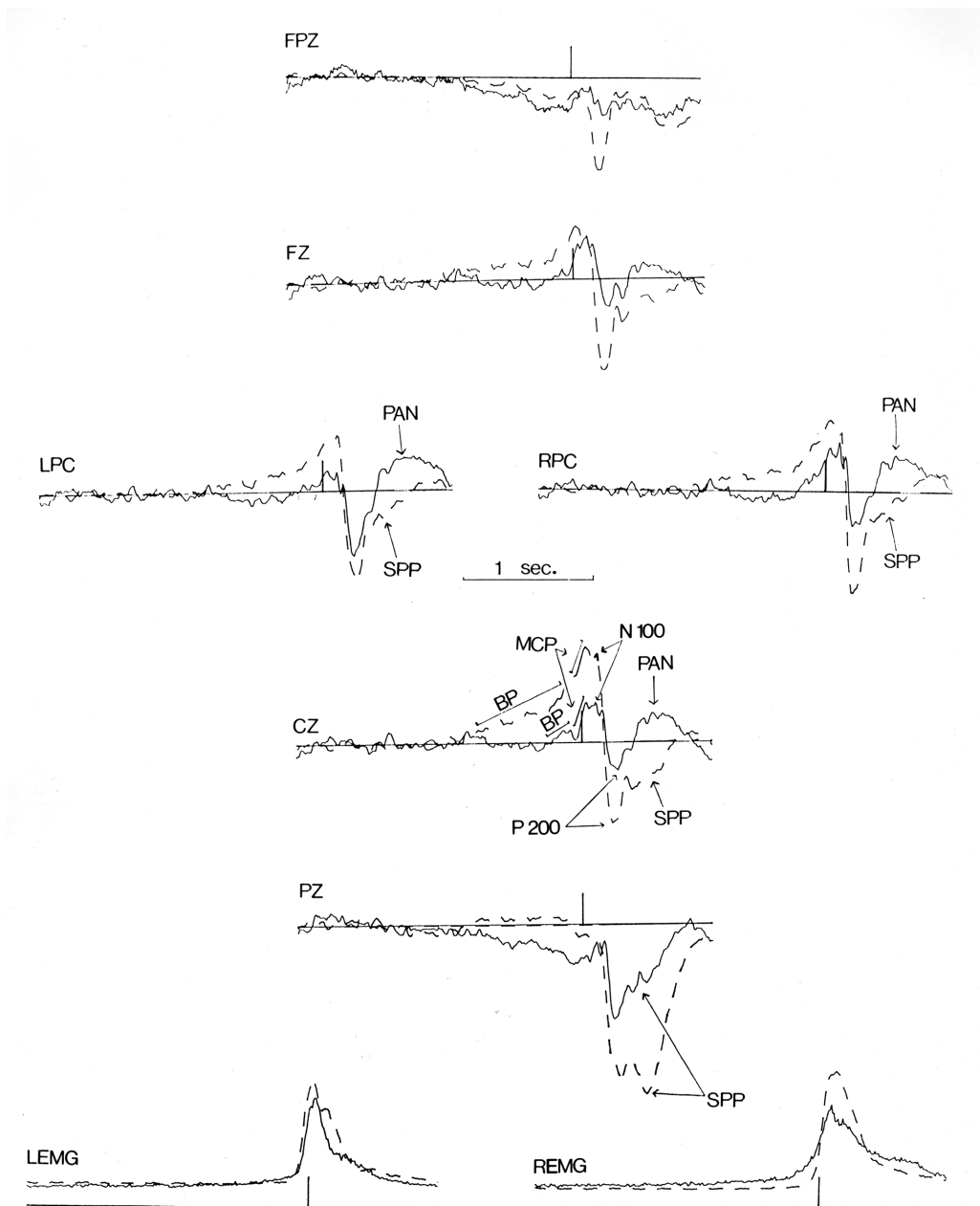


Figure 13.1 Average movement-related brain potentials elicited during the execution of a complex motor-perceptual task, in healthy subjects (thin line) and dyslexic subjects (thick line), recorded at Fpz (Fpz = central prefrontal), Fz (Fz = central frontal) and Pz (Pz = central parietal), along with (bottom) arm electromyographic activity (EMG). BP = Bereitschaftspotential; MCP = Motor Cortex Potential, SPP = Skilled Performance Positivity; PAN = Post Action Negativity. In this figure and in Figures 13.2 and 13.3, the vertical bar is the trigger point that corresponds to the pressure of left button and the appearance of the sweep trace on the oscilloscope screen. From this point the N100 latency of P200, SPP and PAN have been measured.

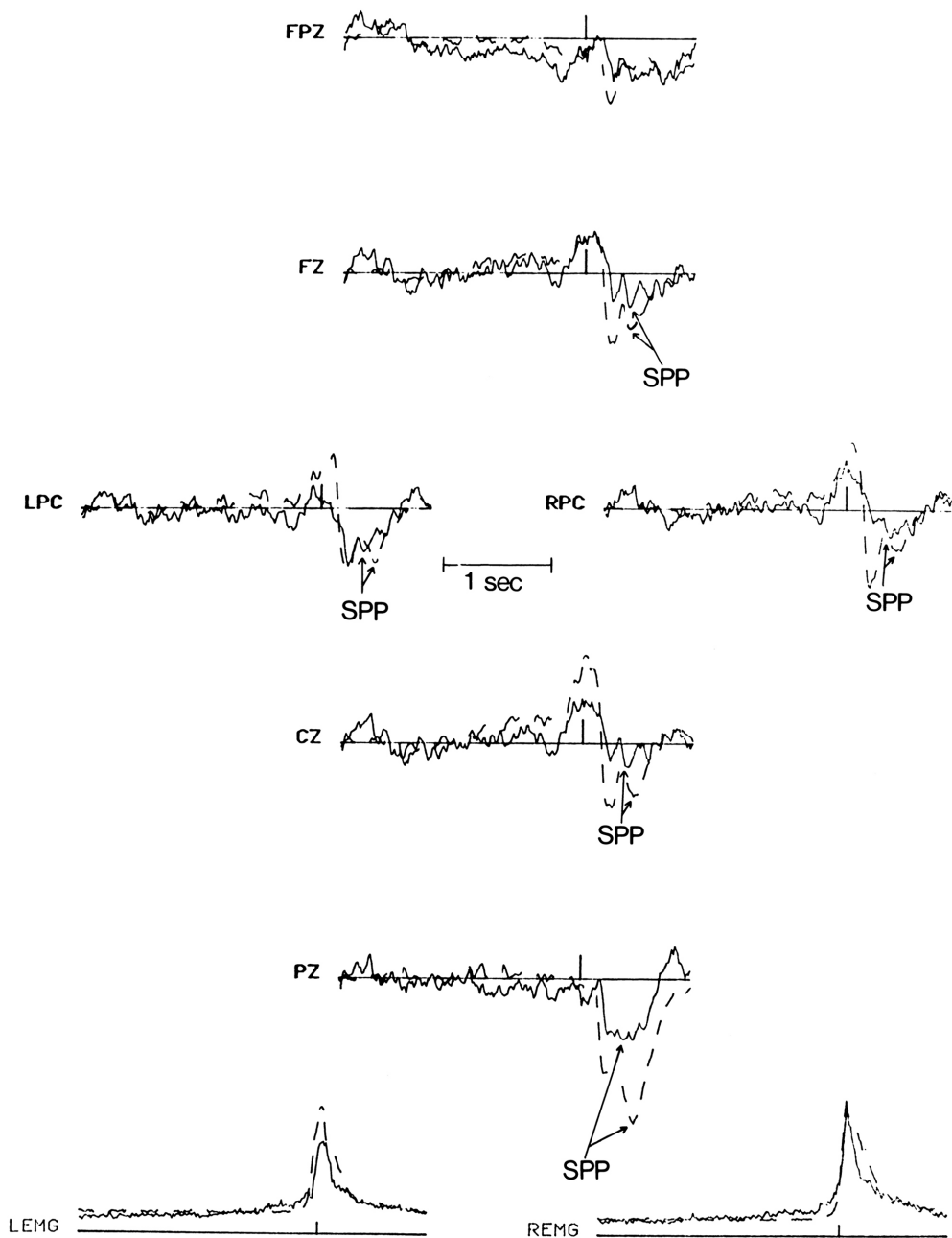


Figure 13.2 Average of movement-related brain potentials associated with target performance in healthy subjects (dashed line) and dyslexic subjects (continuous line). The potential associated with knowledge of results (SPP) is present in all areas of the brain but is reduced in amplitude.

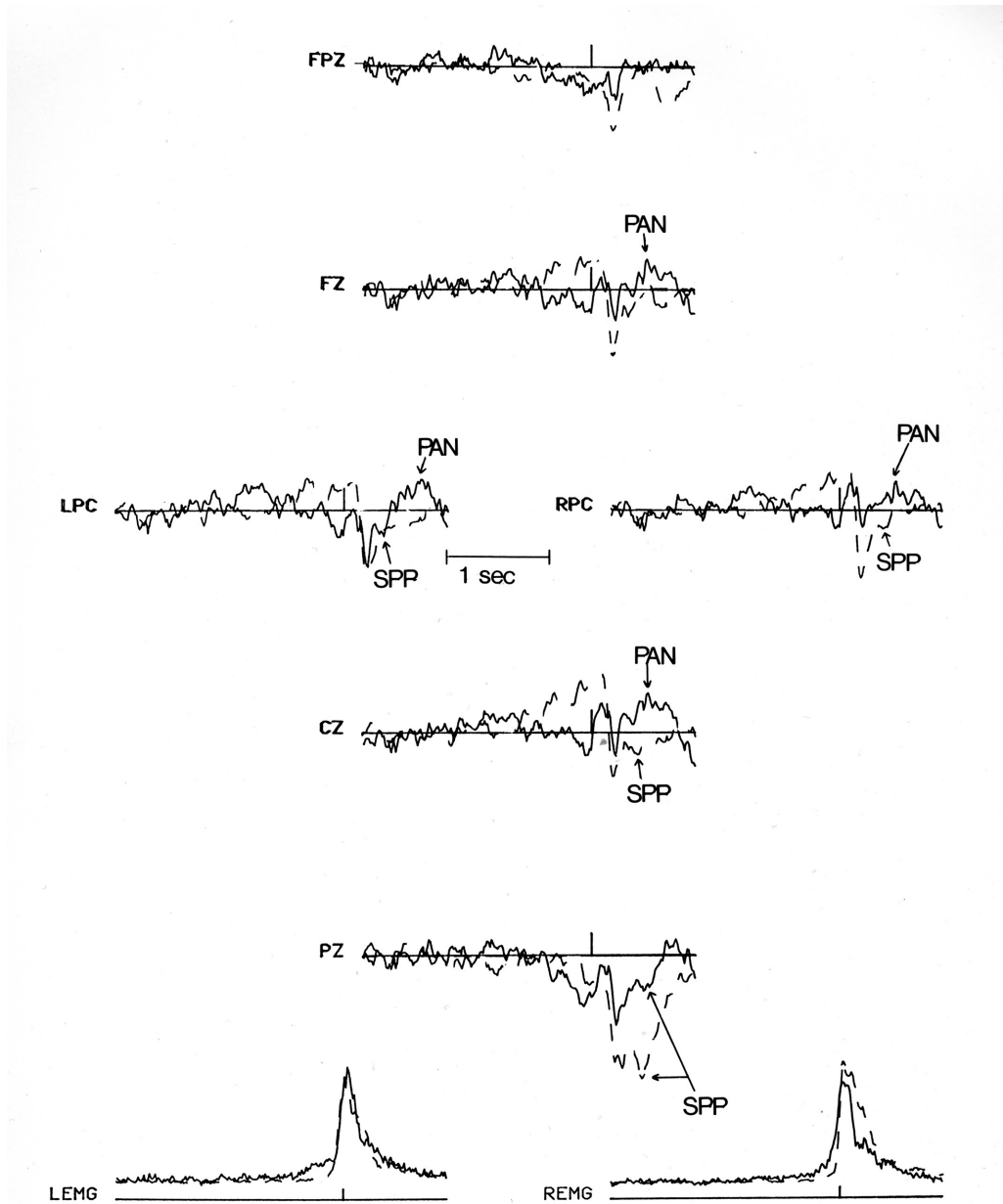


Figure 13.3 Average of movement-related brain potentials associated with non-target performance in healthy subjects (dashed line) and dyslexic subjects (continuous line). The potential associated with the assessment (SPP) is only present at the parietal areas (perceptual activity), whereas at central and frontal areas, a negative potential (PAN) is evident, which reflects failure to process the error (Chiarenza, 1990).

speech. For these reasons, we developed two different tasks to differentiate among the sub-processes involved in reading and evaluated the corresponding RRP's modifications. The first task, defined *passive*, consists of simply "looking" at visually presented letters. The passive task was useful to evaluate the role of perceptual processes only and the potentials were considered as a baseline in the comparison with those obtained during *active* task. The active task consists of reading aloud self-paced letters. The self-paced condition is the most similar to spontaneous reading and allows therefore investigating not only perception, attention and articulation, but also programming and intention altogether involved in reading processes. This task allows the subject to intentionally and autonomously decide when reading. In fact, reading is essentially a voluntary phenomenon. Moreover, in this task we assumed that the subject maintained a constant level of attention that could be more variable during passive condition. We decided to use isolated characters instead of entire words for overcoming the complexities of letters association and fusion into syllables. The presentation of isolated letters simply involves the perception of a letter's graphic shape, the association of a single character to a sound and its production, and therefore allowed us to evaluate the simplest unit of grapheme-phoneme association. The short duration of the stimuli (5 ms) was chosen for testing the ability of subjects to perceive the graphic shape of letters as a *gestalt* that is supposed to be already completely acquired by 6-year-old children at the end of the first grade. Five millisecond greatly recruited subjects' attention, cooperation and motivation, while longer persistence would have reduced task difficulty. Furthermore, the perception of characters with very short duration elicits foveal vision and limits eye saccadic movements that are critical sources of artifacts. Furthermore, the use of words would have inevitably introduced a semantic interference, thus additionally complicating RRP's morphology. Neuro-pathological studies have shown that identification of letters is an early predictor of later reading success and distinguishes adult dyslexics (Flowers et al., 2004). The use of this pre-lexical skill is expected to be helpful for highlighting the neurobiological and functional basis of reading in both healthy and impaired readers. The mean interval between appearance of the letters and onset of speech during self-paced letter recognition was 719.37 ± 125.9 ms. Moreover, accuracy of letter reading (percentage of correctly read letters) was $95.9\% \pm 4.2\%$ during self-paced letter recognition.

Following this approach, it is possible to identify and describe a series of waves and positive and negative peaks that appear before, during and after reading aloud (Chiarenza et al., 2013). These components can be divided into different periods as is shown graphically in Figure 13.4.

The preparatory period includes the electrical activity of the brain that precedes the phasic electromyography (EMG) linked to the button press: this brain activity is represented by the Bereitschaftspotential (BP), which slowly increases its amplitude for a duration of about 500 ms over frontal, central and precentral regions. It has been proposed as an index of the subject's intention to start reading.

The brain potentials that appear in the interval between the EMG activity of the right thumb and the EMG activity of the lips are the Motor Cortex Potential (MCP), P0, N1 and P1. These potentials are related to the appearance of the letter of the alphabet on the screen for 5 ms, and belong to the pre-lexical period. In particular, the MCP recorded over the precentral cortex is related to proprioceptive sensory information of the movement coming from skin joints and muscles. Instead, the potentials P0, P1 and N1 are the expression of the early stages of visual perceptual processing of letters that occur mainly in the occipital and parietal areas.

The N2, P2, N3, P4, N4 and N areas that appear during the ascending limb of the EMG lip activity, belong to the period of reading aloud, which is called the lexical period. They are mostly recorded in the frontal, precentral and central areas. Because these components are elicited during the explicit verbal production of the subject, they are thought to be related to the activation of reafferent activity and control mechanisms.

The components that are located along the descending limb of the EMG lip activity (P600, and L area), when the subject has completed reading, belong to the post-lexical period: they are most represented on posterior parietal regions. It is assumed that these components are related to mnemonic

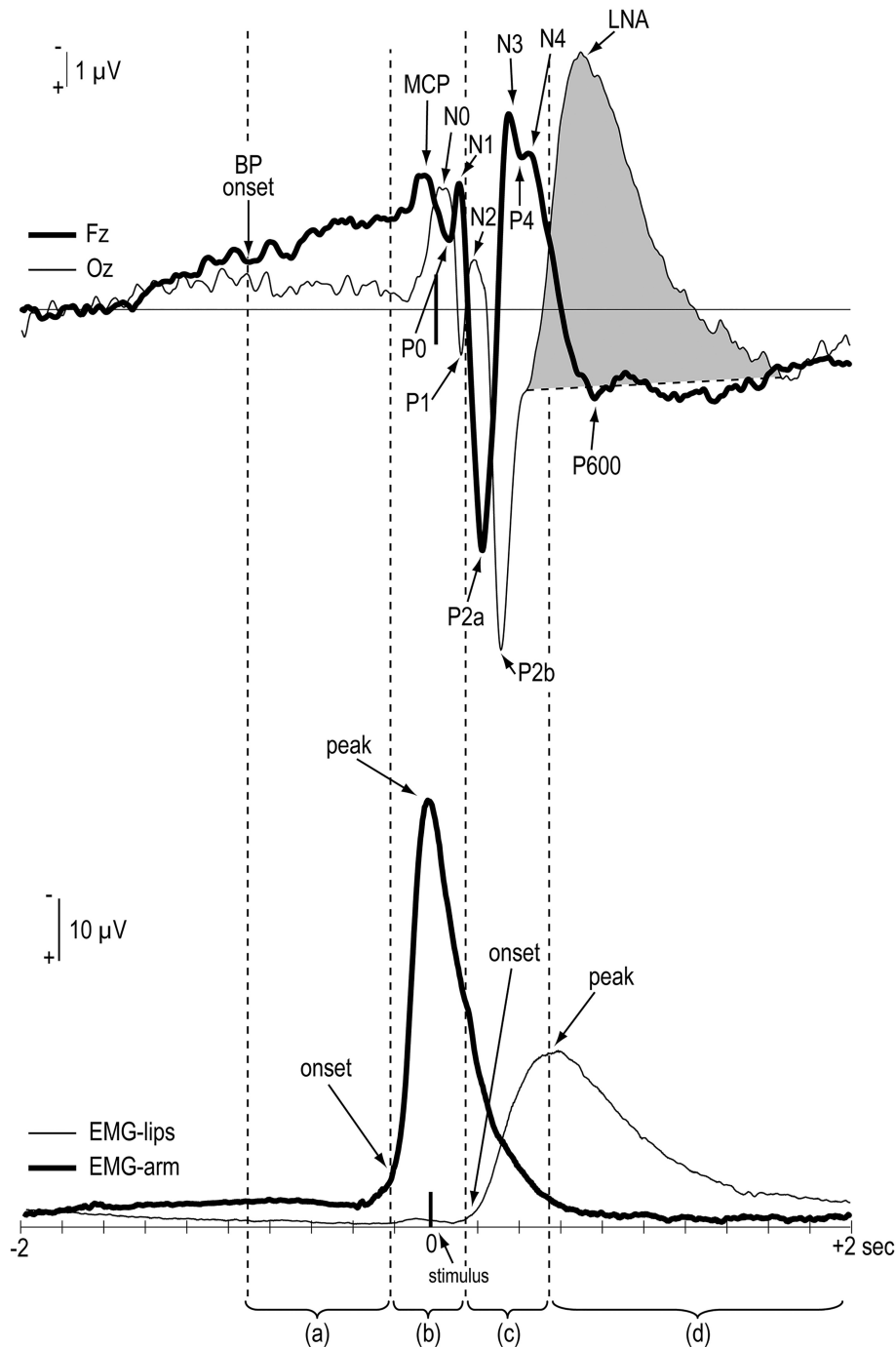


Figure 13.4 Chronology of reading-related potentials. Outline of the chronology of (top) reading-related potentials during self-paced letter reading, recorded at Fz (thick line) and Oz (thin line), associated with (bottom) the electromyographic activity of lips (EMG-lips, thin line) and forearm (EMG-arm, thick line). Reading-related potentials were classified into four periods: (a) preparatory, (b) pre-lexical, (c) lexical and (d) post-lexical period. Bereitschaftspotential = BP; MCP = motor cortex potential; LNA = late negative area. Subject's right thumb press, which triggers letter appearance, was bipolarly recorded from the right forearm flexor muscles (EMG-Arm). Lip movements were bipolarly recorded by two electrodes placed on the superior and inferior orbicularis oris muscles (EMG-lips).

and feedback mechanisms which help in teaching the subject to read. The activation of attention mechanisms is definitely present in each of the periods described above. This is manifested mainly during the pre-lexical and lexical period through an increase in the amplitude of P1 and P2, and a reduction in the latency of P2.

These reading-related potentials recorded from healthy children have been analyzed with sLORETA (Pascual-Marqui, 2002), in order to obtain distributed source images of neural activity from scalp recordings (Casarotto et al., 2007a). In particular, significantly different patterns of activation were observed when comparing self-paced reading aloud to passive viewing of single letters (Figure 13.5). During self-paced reading aloud, functional brain activity was significantly higher in the left supramarginal gyrus and middle-inferior parietal lobule before 150 ms; in the right angular gyrus and middle-inferior temporal lobe between 150 and 250 ms; in the middle-inferior frontal gyrus bilaterally, between 300 and 400 ms; and in the left ventral inferior temporal gyrus after 600 ms. In contrast, during passive letter viewing, the activation in the right middle-inferior temporal-occipital cortex before 150 ms; in the superior frontal gyrus bilaterally between 150 and 200 ms; in the left middle frontal gyrus between 200 and 250 ms; and in the left occipital gyrus between 300 and 400 ms was significantly greater than during self-paced reading aloud.

These results indicate that voluntary reading aloud requires greater attentive, motor and cognitive effort compared to passive observation of letters. The significantly greater activation of the left supramarginal gyrus at short latencies during self-paced reading aloud may be interpreted as a facilitatory effect produced in regions specifically related to grapheme-to-phoneme association mechanisms in order to improve reading performances. The observed task-related differences at middle and long latencies may suggest that self-paced reading aloud additionally engages some regions in the right hemisphere, homologous to left temporal-parietal cortices related to phonological analysis, and in the bilateral frontal regions, related to higher order cognitive processes that are not required for looking passively at letters.

In order to explore reading-related brain activity with high spatial and temporal resolution at the same time, reading-related potentials and functional magnetic resonance images (fMRI) were recorded during the same experimental protocol in healthy adults (Casarotto et al., 2008). fMRI results showed that the left inferior parietal lobule (BA 7/40) and medial frontal gyrus (BA 6) were specifically activated by alphabetic letters; bilateral pre- and post-central gyri (BA 3/4), left middle frontal gyrus (BA 46) and left superior temporal gyrus (BA 22/47) were additionally engaged during

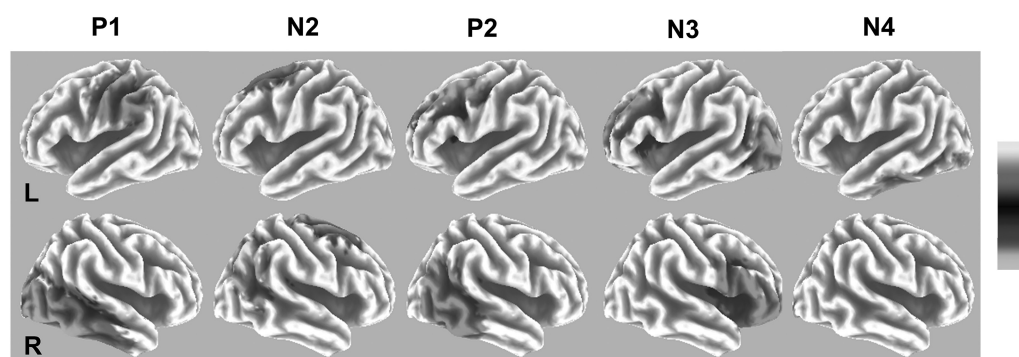


Figure 13.5 Significant differences (paired t -test: $P < 0.01$) between sLORETA maps estimated from reading-related potentials recorded during self-paced reading aloud and during passive viewing of letters. Warm/cold colors indicate that brain activity is significantly higher/lower during self-paced reading aloud as compared to passive observation of letters. L = left hemisphere; R = right hemisphere.

reading aloud. LORETA results showed that neural sources of middle-latency components were observed in the medial frontal areas and middle-superior temporal gyrus bilaterally (BA 22/39) during all tasks. Late components had partially common sources in the middle-superior temporal gyrus bilaterally (BA 21/22/37/39/42).

During both tasks (i.e., passive letter viewing and reading aloud), the cortical region with the widest inter-modality similarities was the middle-superior temporal lobe (BA 19/22/37/39) and the greatest similarities between fMRI and LORETA results were observed during reading aloud of letters. These findings indicate that the role played by the middle-superior temporal gyrus is crucial and multifunctional for linguistic and reading processes. The reason may be related to the fact that it receives inputs from the visual system and strongly interacts with temporal auditory areas. Therefore, its spatial location and its high interconnection with the main sensory system may have favored its specialization in phoneme-grapheme matching (Figure 13.6).

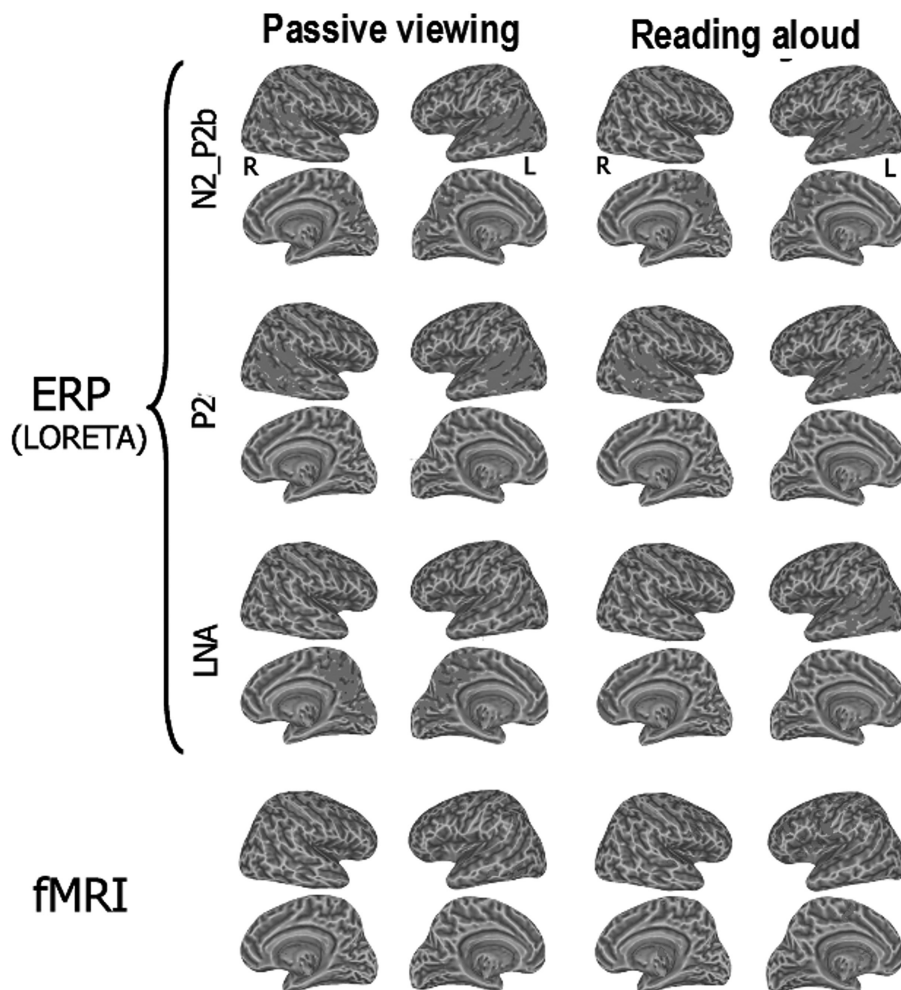


Figure 13.6 Superimposition of functional activations on inflated anatomical cortical surface: lateral and medial views of both hemispheres. LORETA maps (green) of the N2, P2b, P2a, and LNA potentials and fMRI activation maps (red) are reported for the letter and letter reading aloud tasks. L = left hemisphere; R = right hemisphere.

The analysis of reading-related brain potentials has demonstrated that children with dyslexia show an increased latency and a reduction in the amplitude of some components as compared to normal subjects both in the pre- and post-lexical period (Chiarenza, Olgiati, Trevisan & Casarotto, 2006). The differences in the preparatory period represent a non-optimal coordination between motor processes and the intention to read. The anomalies in the pre-lexical components are due to a reduced level of attention and a delay of processing visual sensory information. The difficulties in phonological decoding and verbal articulation of letters can be explained as a failure of phonological and phono-articulatory feedback during the lexical period.

The anomalies of the post-lexical components likely generate an additional malfunction of feedback processes, which are essential to monitor performance and promote learning. In fact, when a person hears himself or herself while reading aloud, it reinforces the elaboration of the visual-verbal stimulus at a cognitive level and reinforces the map of the correspondence between phonemes and graphemes. These abnormalities in latency and amplitude of the cognitive potential associated with reading reflect at a neurophysiological level the behavioral observations made on dyslexic children, which reveal reduced fluency and increased reading time.

The comparison between reading-related potentials recorded during single-letter self-paced reading aloud from healthy children and children with dysphonetic dyslexia (Figure 13.7) shows that abnormal activation in the subjects with dyslexia was present at short latencies in the left temporal polar area, at middle latencies involving temporal polar and inferior frontal regions bilaterally and at long latencies clusters in fronto-temporal regions of the right hemisphere (Casarotto et al., 2007b). This result is consistent with previous findings of greater recruitment of regions in the right hemisphere in dyslexic children in comparison with controls. It suggests further that early involvement of frontal regions and significantly higher activation of the right hemisphere are likely related to compensatory mechanisms adopted by reading-impaired children in order to improve their performance. Impaired neural activation of the dyslexic group was located in left and medial parietal regions: at short-middle latencies, impaired activation was present in the angular and then in the supramarginal gyrus; whereas at long latencies, impaired activation moved in the middle precuneus and occipital lobe. Behavioral signs of reading impairment can be related to reduced activation in the left dorsal parieto-occipital regions that have been shown to be specifically involved in reading processes and particularly in the storage and processing of the visual and auditory representations of alphabetic characters.

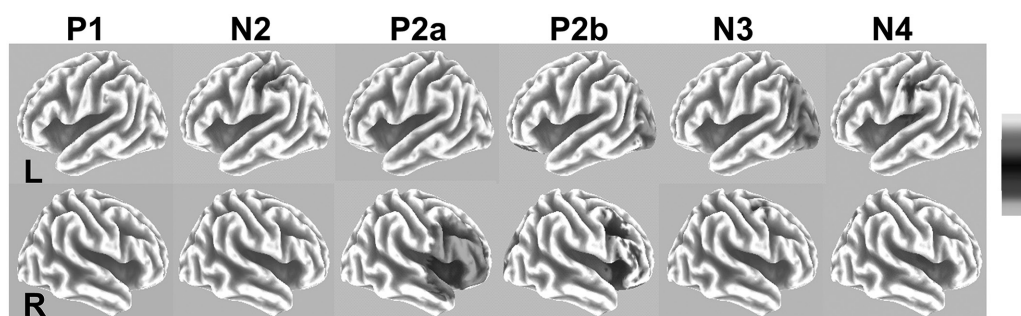


Figure 13.7 Significant differences (unpaired t -test; $P < 0.05$) between sLORETA maps estimated from reading-related potentials recorded during self-paced reading aloud in healthy and dyslexic children. Warm/cold colors indicate that brain activity is significantly higher/smaller in controls as compared to dyslexics. L = left hemisphere; R = right hemisphere.

These findings suggest that dyslexia is not simply caused by a perceptual deficit, but is a more complex disorder associated with a malfunction of higher cognitive functions, including attention, phonological analysis, verbal-motor coordination, control mechanisms and feedback, and memory. These malfunctions seem to be closely and causally related to each other.

Independent component analysis (ICA) of 2–5 minutes of resting EEG obtained for the classical frequency bands and applied to a customized child MRI template and separately calculated for each clinical subtype showed that two types of ICA-based cluster centroids were observed. One was common to different clinical subtypes and could be attributed to a default mode network; the second was cluster centroids linked only with a certain subtype of developmental dyslexia. A cluster centroid in anterior cingulate cortex (ACC) for theta band was present only in the dysphonetic group. Cluster centroids located in the left lingual gyrus, in the beta band and in the thalamus in the theta band were present only in dyseidetic group. In the “mixed” group, cluster centroids distribution overlapped partially with distribution of both dysphonetic and dyseidetic. The “mixed” group additionally had cluster centroids in the right precentral gyrus (in the theta and beta bands) and in the left superior temporal gyrus in the beta band (Velikova & Chiarenza, 2012). These findings provide additional neurophysiologic evidence for the existence of subtypes of developmental dyslexia and pave the way for targeted-made approaches to rehabilitation.

Conclusions

Dyslexia can be defined from a psychophysiological point of view, as a disorder of programming and integrating ideokinetic elements, associated with a deficiency in the fast processing and integration of sensory information, with a reduced efficiency of error systems analysis. All these phenomena occur at different levels of the central nervous system and at different times during reading (Chiarenza, 1990; Chiarenza et al., 1982a, 1982b, 1986).

The combination of these disorders leads individuals with dyslexia to read more slowly than healthy subjects, and to commit more errors. The specific characteristics allow us to establish a close correspondence with the Boder (1973) model of reading and writing, and to emphasize the great importance of taking into account the models of different subtypes of dyslexia.

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