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The psychophysiology of reading

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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.

1. 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.

2. Dyslexia clinical features

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, Kinsbourne and Warrington (1963) have outlined

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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 and Coltheart, 1992).

2.1. Dyslexia clinical subtypes

Boder (1973), inspired by the studies of Benton (1962), Birch and Belmont (1964), Bannatyne (1966) 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 and 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 its 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 (Chiarenza and Cucci, 1989; Chiarenza and Bindelli, 2001; Chiarenza et al., 1990, 1992, 2004, Bindelli et al. 2001). 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 kinaesthetic motor processes are essential prerequisites for fluent reading and writing.

Another clinical aspect of dyslexia that has been littly 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 has long been observed in dyslexic children (Fog and Fog, 1963; Abercrombie et al., 1964; Connolly and Stratton, 1968; Denhoff et al., 1968; Lewis et al., 1970; Pyfer and Carlson, 1972; Bruininks and Bruininks, 1977; Owen et al., 1971; Klicpera et al., 1981). Furthermore, clinical signs such as dysrhythmia, the presence of synkinetic movements, have often been described in dyslexic individuals (Adams et al., 1974; Kennard, 1960; Rutter et al., 1966; Stine et al., 1975; Wolff and Hurwitz, 1973; Denckla, 1973). These difficulties were interpreted as a disorder of the temporal organization of motor skills (Klicpera et al., 1981; Denckla, 1973). These observations were also recently confirmed by Punt et al. (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 the 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 the phenomena that take place before and after it. This is the fundamental and unique contribution of cognitive psychophysiology.

3. 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 et al., 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 40–60 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