METHODOLOGICAL, DEVELOPMENTAL AND CLINICAL ASPECTS OF MOVEMENT RELATED BRAIN MACROPOTENTIALS

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Critical review

SUMMARY - Methodological, developmental and clinical aspects of movement related brain macropotentials are reviewed. Physiological differences of unskilled and skilled movements are described and the importance of interactive paradigms in studying movement organization from childhood to the adulthood is emphasized. Developmental characteristics of movement related brain macropotentials in 119 subjects using skilled motor perceptual task are presented together with a few clinical applications. Children with learning disabilities and with Down's syndrome are compared to normals. Movement related brain macropotentials of chronic schizophrenic patients and of those with Parkinsonism are described and their possible contribution to better understanding of these two clinical entities and their therapeutic implications are outlined.

Key words: movement related potentials, Bereitschaftspotential, skilled performance

Introduction

Awaiting an event and recognizing and responding to it produces changes of the whole person, i.e. of his central, peripheral and autonomic nervous systems.

Jasper and Andrews (1938) were the first to observe that the tactile stimulation of one part of man's body blocks electrical activity of the motor cortex contralateral to the stimulated side. Eleven years later, Jasper and Penfield (1949) using cortical recordings noticed that voluntary movements had the same blocking effect. This block was present in the contralateral precentral area before and after the movement. Later, Penfield (1954) concluded that "the contralateral blocking of the wicket or beta rhythm preceding spontaneous movement suggests that while the patient is planning a given movement, a stream of impulses flows from some cortical or subcortical positions to the motor cortex of the opposite hemisphere, the blocking of the wicket rhythm being thus caused. This may have the effect of preparing the precentral area for action, probably by increasing its susceptibility to more elaborate volitional messages resulting from complex integrations, which supply to the motor neurons the plan of movement in the form of spatially and temporally varied patterns of impulses." This view of the motor action as a complex and integrated phenomenon assuming preparation and control processes over the movement itself remained isolated, although later research confirmed Penfield's observation through scalp recordings as well (*rhythme en arceau*: Gastaut 1952, Klass and Bickford 1957; μ *rhythm*: Chatrian et al. 1959).

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There were mainly two reasons for this: on the one hand, development of the computer technology was still far ahead and, on the other, classical animal physiology studied movements mainly as a response phenomenon to stimuli. The reason is that studying voluntary movement in animals still presents remarkable theoretical as well as methodologic difficulty. Thanks to the advancement in technology, it was possible to time-lock behavioural phenomena to the cerebral electrical events and thus to study changes in the intrinsic rhythm, as well as phasic and sustained brain potentials related to movements. Postcentral rhythm has at rest greater amplitude than the precentral one. Passive movement abolishes only the precentral rhythm, whereas voluntary movement abolishes both (Papakostopoulos et al. 1980). In 1965, Kornhuber and Deecke observed that passive finger movement 52 ms after its onset produces on the scalp a series of 7 peaks. The first 5 were recorded mainly contralaterally and the last 2 mainly homolaterally to the moving finger. The delay between the late peaks was approximately 140 ms. These potentials are thought to be an expression of the kinaesthetic feedback coming from the skin, joint and muscle receptors (Shibasaki et al. 1980). On the other hand, a brisk voluntary self-paced flexion of a finger produces on the scalp a series of brain potentials which precede and follow the movement. In spite of the possibilities offered by the development of technology and although the experimental evidence suggested that human movement occurs through integration of the perceptive, sensory-motor and cognitive processes, brain motor potentials have been analyzed in a purely descriptive way. They were evoked by simple unskilled finger or toe movements, repeated hundreds of times (Papakostopoulos 1978b, 1980a). An attempt at finding neurophysiological correlates of the proposed preparatory, executory and control motor mechanisms was done. During the unskilled single manual tasks, Bereitschaftspotential (BP) is generated (Kornhuber and Deecke 1965) and is proposed to be an index of the preparatory processes. Premotion positivity (PMP) (Deecke et al. 1969) indicates movement initiation, while motor potential (MP) indicates pyramidal cell discharge (Deecke 1978). Motor cortex potential (MCP) signifies reafferent activity generated in response to voluntary movement (Papakostopoulos et al. 1975).

Behaviour psychologists consider motor performances as an execution of a plan organized by brain in the absence of the external stimulus. It is assumed also that these internally programmed plans are updated by means of external feed-back (visual or auditory information), or by information coming from the inner environment (kinesthetic, proprioceptive), both informing the subject of the result of his actions. Several models have been proposed by behaviour psychologists (Bernstein 1967; Bruner 1970; Schmidt 1975).

Complex motor tasks were in 1978 introduced also into physiology. They required particular ability, were goal-directed, interactive, "skilled", and enabled the subject to update his motor strategies, after he had learned the results which were fed back to him on-line (Papakostopoulos 1978a, 1980a; Taylor 1978). Using a self-paced, goal-directed bimanual tasks, Papakostopoulos recorded what he defined as Movement Related Brain Macropotentials (MRBMs). On the basis of their relation to EMG activity and in comparison to motor potentials during unskilled movements he subdivided them into 4 periods. These 4 periods were premotor, sensory-motor, motor completion and post-motor periods (Papakostopoulos 1978b). Figure 1 shows a detailed diagram, recently updated by Chiarenza (1989), of the sequence of electrical brain events accompanying execution of the task.

Premotor period is characterized by the tonic muscle activity and by phasic negative potential lasting 800-1500 ms. It is called "Bereitschaftspotential" (BP) (Kornhuber and Deecke 1965), or readiness potential (Vaughan et al. 1968). BP is symmetrically distributed over the hemispheres, at least during the first second; 500 ms before the EMG onset, it is in unimanual tasks more pronounced contralaterally to the movement side in both right- and left-handed subjects. It has smaller (5 to 7 μV) amplitude during simple tasks and greater amplitude during more complex tasks, independently of the amount of EMG activity and of muscle strength used with both adults (Papakostopoulos 1978a) and children (Chiarenza et al. 1980). It is mainly recorded in the frontal, precentral and central regions. BP does not change in its amplitude if the subject receives visual feedback of the results of his performances (Papakostopoulos et al. 1986). The negativity decreases with age. This process starts after the fourth decade and the potential becomes positive around the sixth decade. These observations were made during unimanual unskilled tasks (Deecke 1978). No differences in the BP amplitude between the old and young subjects were detected during skilled tasks (Papakostopoulos and Banerji 1980). Bimanual skilled tasks are accompanied by symmetrical BPs in the right-handed subjects and by asymmetrical ones in the left-handed subjects (greater on the right precentral regions) (Papakostopoulos 1980b). For any type of movement greater BPs are observed at the vertex, what, according to Boschert et al. (1983) and Boschert and Deecke (1986), reflects activity of the supplementary motor area. BP is considered as an indicator of the cerebral activity concerning organization and selection of the strategy needed to carry out a planned action through an early preparatory process of the thalamocortical facilitation.

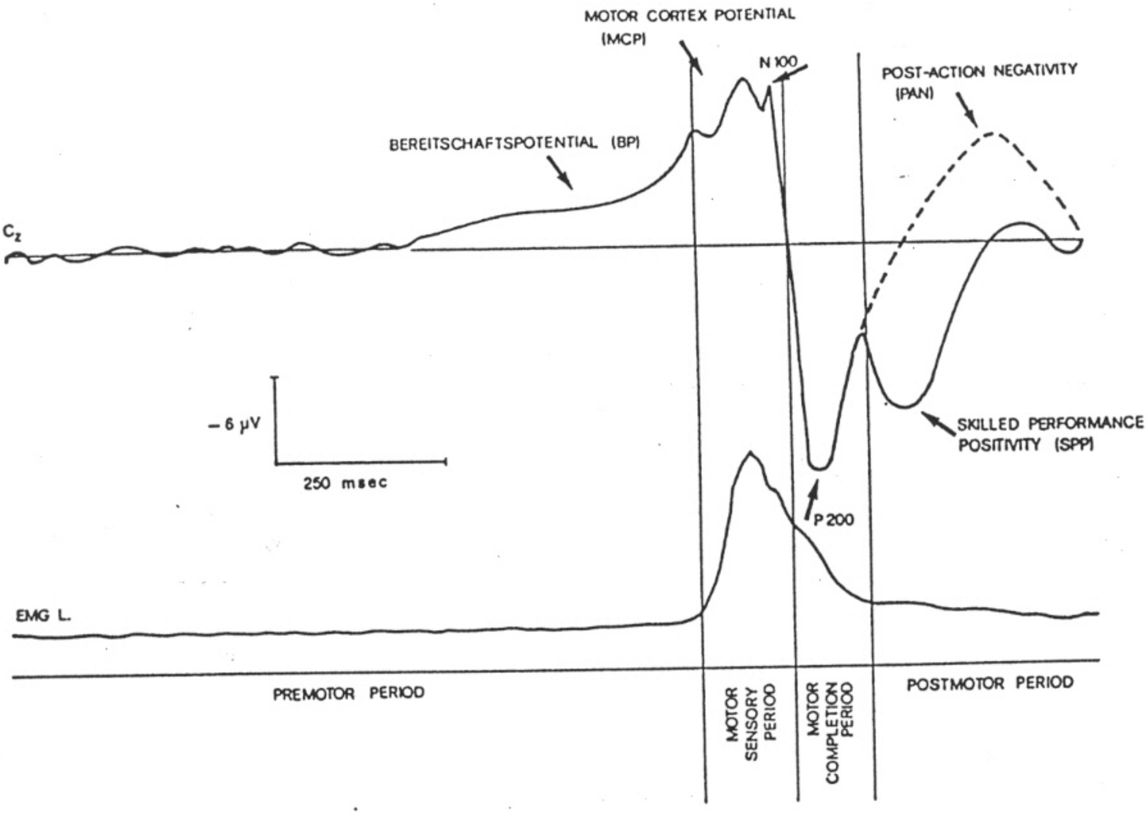

Figure 1. Schematic diagram of movement related brain macropotentials related to the motor perceptual task.

Sensory-motor period begins at the onset of phasic EMG activity and lasts for about 200 ms. It is during this period that the actual motor performance is carried out. It coincides with the appearance of motor cortex potential (MCP), and N100. MCP is a negative potential which follows BP. It is present during the unskilled actions and increases in amplitude during self-paced, ballistic and sustained motor performance (Grunewald et al. 1979; Papakostopoulos 1978a). Scalp and cortical recordings have shown that the MCP is recorded in the precentral and central regions mainly and is absent from the parietal regions (Papakostopoulos 1980a; Papakostopoulos and Crow 1984). MCP represents response-generated (re)afferent activity from the muscle, skin and tendon receptors (Papakostopoulos et al. 1975). It is present in children and adults. Its amplitude decreases with senescence (Papakostopoulos and Banerji 1980). N100 wave has a latency of 100 ms and follows the MCP. It is a response evoked by the appearance of the oscilloscope trace and is during movements normally inhibited in the frontal and postcentral areas.

Motor completion period starts when the electromyographic phasic activity stops. It consists of a positive potential defined as P200 that follows N100 with a latency of about 200 ms from the beginning of the light stimulus (Vaughan et al. 1968). This potential is present during the passive and self-paced movements, both simple and complex, and is on the basis of its developmental course believed to be one of the components of the reafferent somatosensory potentials (Chiarenza et al. 1983).

Post-motor period is marked by electromyographic tonic activity similar to the premotor period, by the appearance of a positive potential with a latency of about 450 ms ("skilled performance positivity" - SPP) (Papakostopoulos 1978a, 1980a), and by a slow negative potential ("post-action negativity" - PAN) with a latency of about 600 ms (Chiarenza et al. 1983). The SPP has greater amplitude in the parietal regions and appears approximately at the age of nine years in the fronto-central regions (Chiarenza 1986b). Scalp and cortical recordings have shown that the SPP is present only when the subject expects and receives an on-line feedback of his performance (Papakostopoulos 1980a; Papakostopoulos et al. 1986). This potential is independent of the motor action and of the presence of any exteroceptive stimulation; it coincides with the subject's awareness of success or failure of the performance (Chiarenza 1986a, 1986b; Papakostopoulos 1980a). Post-action negativity has specific spatial distribution (is recorded mainly in the fronto-central regions), and decreases in amplitude with age until it disappears around the tenth year of age (Chiarenza et al. 1983). As the SPP, PAN is also independent of motor action and seems to be related to the analysis and evaluation strategies different from those generating SPP (Chiarenza et al. 1984). The presence of these positive and negative potentials was confirmed by other authors (Elbert et al. 1986; Foit et al. 1982; Grunewald et al. 1979; Knapp et al. 1980; Netz et al. 1984; Taylor 1978; Weinberg 1980).

It is clear from these experiments that self-paced goal-directed motor performance consists of various motor, sensory and cognitive subsets located at different sites of the brain. They probably operate in parallel and may vary independently of one another but should be considered as "integral formations" Bernstein (1967). Thus their separation would appear to be purely artificial.

Method

Skilled Motor-Perceptual Task (SMPT). The subjects were sitted in an armchair 70 cm in front of an oscilloscope. The room was lighted and electrically insulated. Subjects held joystick-type push-button in each hand. Trip of the button was 5 mm. The task consisted of starting the oscilloscope sweep with the left thumb and stopping it in a predetermined area of the oscilloscope by pushing the other button with the right thumb. Sweep velocity was 1mm/ms. The target area was readied in 40 and 60 ms. Subjects had to learn to predict this minimum time available and program the whole motor sequence in advance, as well as update their own plans on the basis of the results they obtained.

After verbal explanation of the task, subjects were allowed short practice period to ensure that all of them understood verbal instructions and could start from the same level of practice. Recording procedure was initiated only after subjects were able to stop the oscilloscope sweep at least twice in the 40-60 ms interval. This practice was also necessary to enable subjects to learn to control eye-movements and blinking during execution of the task and to keep an interval of 7 to 20 s between any two attempts. Subjects were also asked to relax during the task and to avoid muscle preparatory movements before pressing.

Recording Procedure. Silver chloride electrodes were fixed to the scalp with collodion in the prefrontal (Fpz), frontal (Fz), central (Cz), right precentral (RPC), left precentral (LPC) and parietal (Pz) regions. Reference electrodes were placed bilaterally to the mastoids. Electromyogram was recorded with the surface electrodes from the flexor muscles of both forearms. The impedance of electrodes was less than 3 kOhm. Time constant and high frequency filters were set at 4.5 s and 700 Hz for the EEG and 0.03 s and 700 Hz for EMG.

EEGs and EMGs were stored on the FM magnetic tape for the off-line analysis. During the analysis, on reception of the trigger pulse obtained from an electric pulse generated on pressing the left-hand button, 3.2 seconds for each channel were sampled at a rate of 250 Hz. Of these, 2.2 seconds preceded the trigger pulse and 1 second immediately followed it. An average of the first second was then taken to establish the baseline from which the amplitudes of the various potentials were measured. All values were normalized to the calibration signal detected and stored on the disc.

Data Analysis

Performances. Time interval between the two pressings (performance time) was measured. Distance from the target was also measured and called "performance shift." Number of performances reaching the target was called "target performance." Number of performances under 40 ms and over 60 ms was referred to as "wrong performance."

Movement-related brain macropotentials. For each subject, four blocks of 25 sequential trials free of muscular artifacts, blinking or eye-movements were averaged and measured. In addition, each performance was allocated in different performance intervals (interval 1: 0-20 ms; interval 2: 21-39 ms; interval 3: 40-60 ms; interval 4: 61-80 ms; interval 5: 81-100 ms; interval 6: 101-125 ms; interval 7: 126-150 ms; interval 8: 151-200 ms; interval 9: > 200 ms) and MRBMs were averaged consequently.

EMG and MRBM measurements. Mean EMG amplitude prior to the movement, its peak amplitude during the movement and rise time of the rectified EMG signal were calculated for both arms after locating EMG onset and its peak amplitude. MRBMs were measured as follows: area of the BP was measured from its onset to the point corresponding to the EMG onset. Mean amplitudes of BPs and motor cortex potentials were computed for 200 ms periods; for the BP immediately preceding left-EMG onset, and for the MCP immediately following it. MCP amplitude was defined as a difference between the BP and MCP amplitudes, measured from the baseline. Latency to the MCP peak was measured with respect to the EMG onset. Amplitudes of the N100 and P200 waves were measured from the baseline and their latencies from the left-hand trigger. Mean amplitudes of the skilled performance positivity and of the post action negativity were taken as average values of 200 ms period centred around the main positive (SPP) or negative (PAN) peaks at latencies of 350 and 850 ms respectively. SPP and PAN latencies were measured from the trigger pulse.

Analysis of the data, unless otherwise specified, was based on variance analysis for multiple linear regression. Age, subjects, and blocks were independent variables and MRBMs and performances dependent variables. Analysis of variance was performed to test significance of multiple regression, yielding F values, and significance of the individual partial regression coefficients, yielding t values.

Developmental Studies

Child's intellectual development passes through several stages, during which the following abilities, action, perception, concrete or abstract thinking, sequentially play the dominant role. Cognitive theories postulate that the motor action is a source of mental operations (Inhelder and Piaget 1958; Fischer 1980). Subject's actions are crucial for acquiring ideas or strategies, which will make his interactions with the environment successful. "I know an object only when I can act on it; before my action, I can say nothing about it". This was Piaget's reply to those who questioned him about the nature of reality and our knowledge of it. Therefore, the developmental study of MRBMs may greatly contribute to the understanding of organization of movement in children and of the development of various cognitive processes associated with it. Such studies may also have possible clinical application deriving from it.

119 healthy volunteers were subdivided according to their age: 17 were 6 years old, 17 were 7 years old, 21 were 8 years old, 17 were 9 years old, 17 were 10 years old, 13 were 11-12 years old, and 8 of them were 13-14 years old. Also were included 9 adult subjects. All the subjects complied with the following requirements: they were right-handed Italian mother-tongue males, with no sensory, visual or auditory defects, no neurologic symptoms, no convulsive disorders, and free from psychopathologic personality disorders. No other things were noted by the investigator which could expose subjects to additional risk or interfere with the research. They all had good school records. In order to check the above mentioned criteria for admission, all children underwent clinical and psychodiagnostic tests prior to the investigation (Chiarenza et al. 1982). These consisted of a detailed history regarding birth and development given by parents, detailed school profile written by teachers, clinical neurologic test based on the Minor Neurological Dysfunction protocol (Towen 1979), as well as of a set of intelligence and motor-perceptive tests including: Two WISC scale Intelligence Tests (Wechsler 1976) and the Culture-Free Cattell Test 2, Form A (Cattell 1951); the Italian adaptation of Oseretsky's Motor Development Scale (Zucchi et al. 1959), laterality tests (Harris 1968); Bender Visual Motor Gestalt Test for Children (Koppitz 1964), Rey's Complex Figure copy and memory test (Rey 1969), Goodenough's Test (Gesell and Amatruda 1974), Draw a Family Test, Stambak's Test (Stamback 1965), Reading and Writing Tests for subjects over 7 years of age, including Recognition Test of meaningful/meaningless words and Spelling Test (Italian version of the Metropolitan Achievement Test, Faglioni et al. 1969, 1970). For 6 year old children, the L1 B.A.S.E. Reading Test (Primary School Set) (Vegetti 1971) and for 7 year old children an objective reading test POL3/67-DIA/B deciphering, POL1/67-ER-I accuracy and speed (Grasso-Magrin and Tornai-Vinciguerra 1969) tests were used.

With the age and exercise performances improve. Performance time decreases, accuracy, expressed as a performance shift, improves and number of the target performances increases. Crucial age appears to be at 10 years, when both the performance shift and the target performance values reach adult values.

MRBM changes follow these age-related changes in performance. Figure 2 shows MRBMs recorded from the prefrontal and central regions for subject groups of different ages.

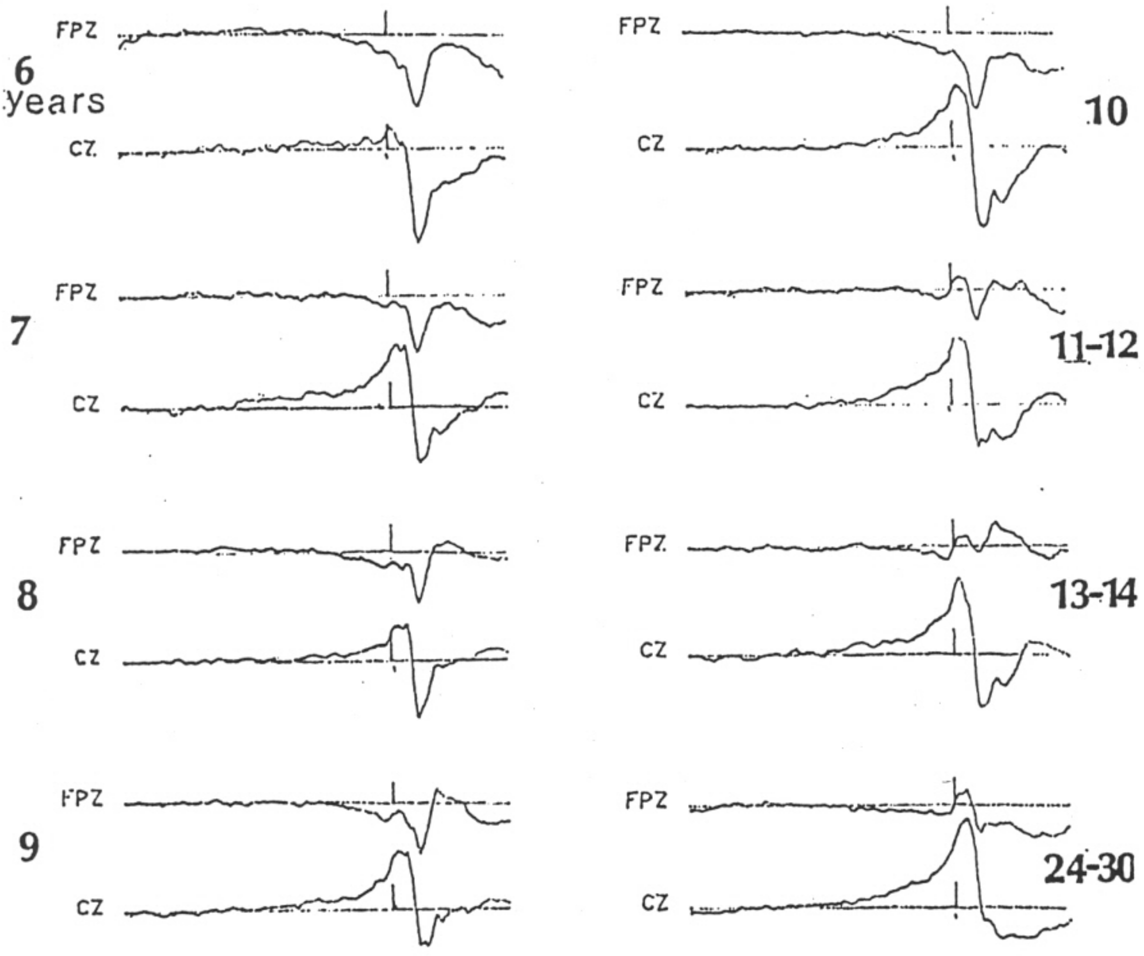

Figure 2. Grand-average movement related brain macropotentials during skilled performance task from prefrontal (Fpz) and vertex (Cz) locations for each age group. The number of subjects for each age group is indicated in the text. In this and all following figures calibration bars (-5 μV) indicate onset of the oscilloscope sweep.

BP appears as a negative wave at about 7-8 years of age. It is first seen in the central and precentral areas. After the age of 10, it appears in the frontal and parietal regions as well. Its amplitude increases with age and significantly correlates with the intelligence and motor development quotients as measured by Oseretsky's scale. Motor cortex potential is present already in 6-year old children, and increases in amplitude with age. It is always recorded in the precentral, central and frontal areas, whilst it is absent from the parietal regions. N100 is present in all subjects and is more easily detected in the parietal than in the frontal and precentral areas. Its mean latency (80-100 ms) decreases with age. P200 appears in various regions of the scalp in all age groups. Its latency is approximately 200-220 ms. The latency decreases and amplitude increases with age. The *skilled performance positivity* is detected in all subjects from the parietal areas only. Absent is in most of them from the frontal, central and precentral areas up to the age of 8-9 years. After the age of 10, SPP in these areas increases in amplitude and decreases in latency. It is known that at the age of 10, the frontal associative areas, particularly the granular layer, accomplish their maturity

(Yakovlev and Lecours 1967). Functional role of these areas is also known to be associated with development of the abstract, formal and probabilistic thought which, according to several cognitive psychologists, takes place just at about this age. This observations are confirmed by examination of the recordings from 7-year old children. MRBMs of the target performances are compared to those of the wrong performances. As can be seen in Fig. 3, SPP is present in both parietal and frontal regions only during the target performances. During wrong performances, both in defect and in excess, SPP is present in the parietal regions only, whilst in the frontal, central and precentral regions post-action negativity (PAN) is observed.

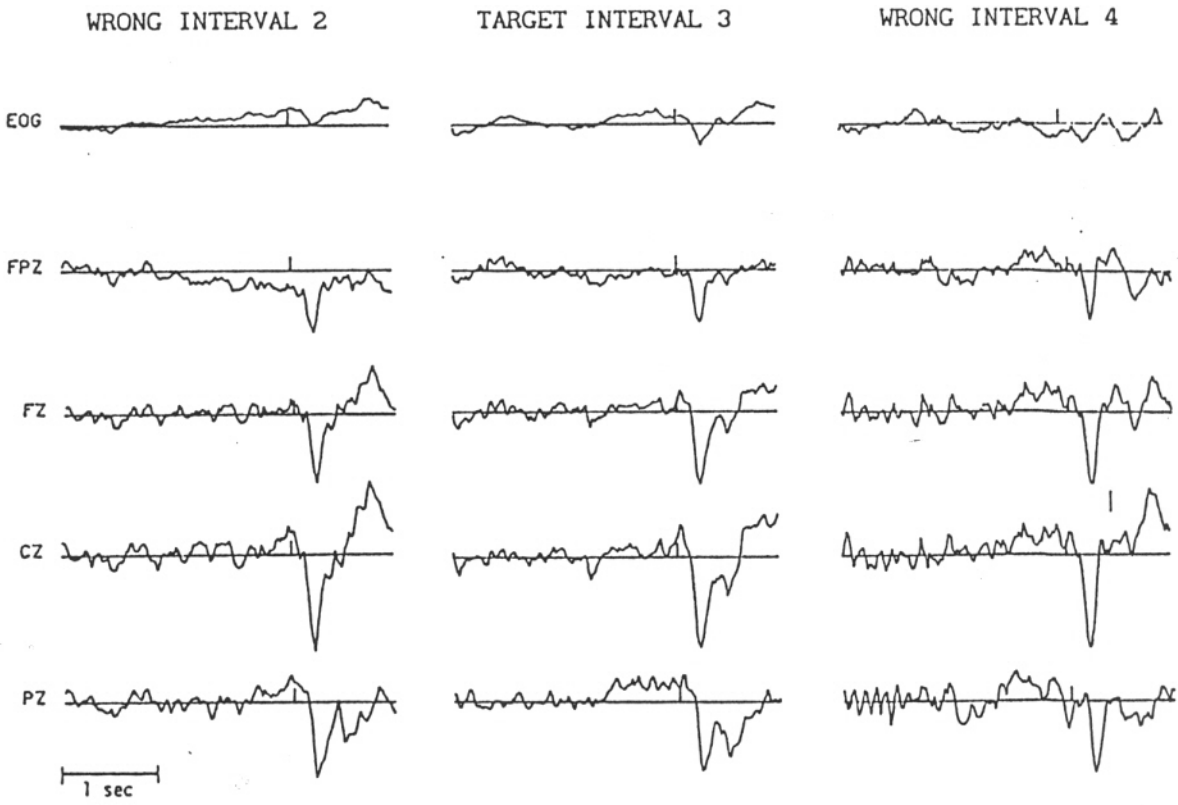

Figure 3. Movement related brain macropotentials of one subject 7 years old averaged according to performance time. For time intervals see the text.

This potential decreases in amplitude with age and seldom appears after the age of 10 (Chiarenza et al. 1983, 1984). These data seem to emphasize different brain operations involved in different tasks. Similar negativities were recorded by Courchesne et al. (1987) through odd-ball type paradigms. When a 6-10 year old child receives an unexpected "novel" stimulus, different from the expected one, negativity is recorded rather than positivity. It may be that in our children discrepancy between the desired and the obtained result produces this negativity which may be an expression of surprise, an unexpected, unwanted event. Interviewing younger children after the task it emerged that the most relevant thing for them is hitting the target, i.e. obtaining target performances. This observation urged us to extend our study to the children over 10 and compare them with a group of adults (Chiarenza et al. 1989). In the frontal and parietal regions, SPP in adults does not show any difference in amplitude which could be related to the result of the motor task. In the 10 year old children the greatest SPP amplitude is observed during the target performances and it decreases in the frontal regions together with the decrease in accuracy. In the adults, SPP latency is smaller during the target performances and greater during the wrong performances, as though the adults care more when they fail than when they succeed. With the children it is exactly the opposite. This type of children's behaviour has often been observed by cognitive developmental psychologists. They claim that 10 year old children have not fully developed formal abstract thinking yet (Fischer 1980; Greenfield and Schneider 1977).

MRBMs, as has been seen, undergo changes with age and are thus sensitive indicators of functional development of the central nervous system and of the related cognitive processes. Performances are known to improve with exercise and moderate but regular practice is thought to be more efficient than an intensive one. For this reason we made an experiment with 9 subjects aged 11-14, with impairments in the perceptive-motor sphere, who carried out 100 performances and repeated them after 1 hour, after 14 days, and after one month. The succession of the 100 trials was considered as an intensive practice, whilst other tests as a continual practice (Villa et al. 1989a, 1989b). With both types of practice accuracy and number of the target performances improved significantly. Effects of exercises on MRBMs were observed only after one month. BP in particular decreased in amplitude and decreased in the onset time over the whole scalp. SPPs, instead, showed significantly shorter latencies in all cerebral regions and significantly higher amplitudes in the frontal and right precentral regions. These results seem to indicate that certain period of time is necessary for the "motor engram" related to the task to be memorized; afterwards, organization of the skilled performance requires less time (decrease in the BP onset time) and smaller effort (reduced BP amplitude); evaluation and memorization of the results become faster, SPP latency smaller and more efficient, and SPP amplitude higher. It is known that mnestic trace storing does not happen abruptly, but occurs gradually after the initial learning phase. This phenomenon of consolidation is apparently due to the presence of reverberating circuits, which increase the efficiency of certain synapses and cause permanent structural changes in them. These changes seem to represent neuronal basis of the long-term memory (Deutsch 1983).

Clinical Applications

Reading and writing are complex and skillful processes that consist of a set of modular subroutines, serially and hierarchically organized. Children with the developmental reading disorders lack control of the perceptual and motor behaviour (Belmont 1980). In order to evaluate these children motor-perceptive psychologic tests are generally used. They require children to reproduce drawings with certain orientation and interrelationship of different objects in space. These tests cannot explain whether perceptive, motor or integrative functions inbetween the visual, auditory, sensory and perceptive kinesthetic systems are really being compromised. Therefore, a method which incorporates measurements of the motor performance accuracy, electromyographic activity and MRBMs during the execution of the skilled motor-perceptual task appears to be particularly qualified to supply useful information on those systems and subsystems which regulate and organize reading and writing functions. Figure 4 compares results from two groups of children aged 10 years. In the first there were 9 normals and in the second 4 children with the developmental reading disorders (Chiarenza et al. 1986).

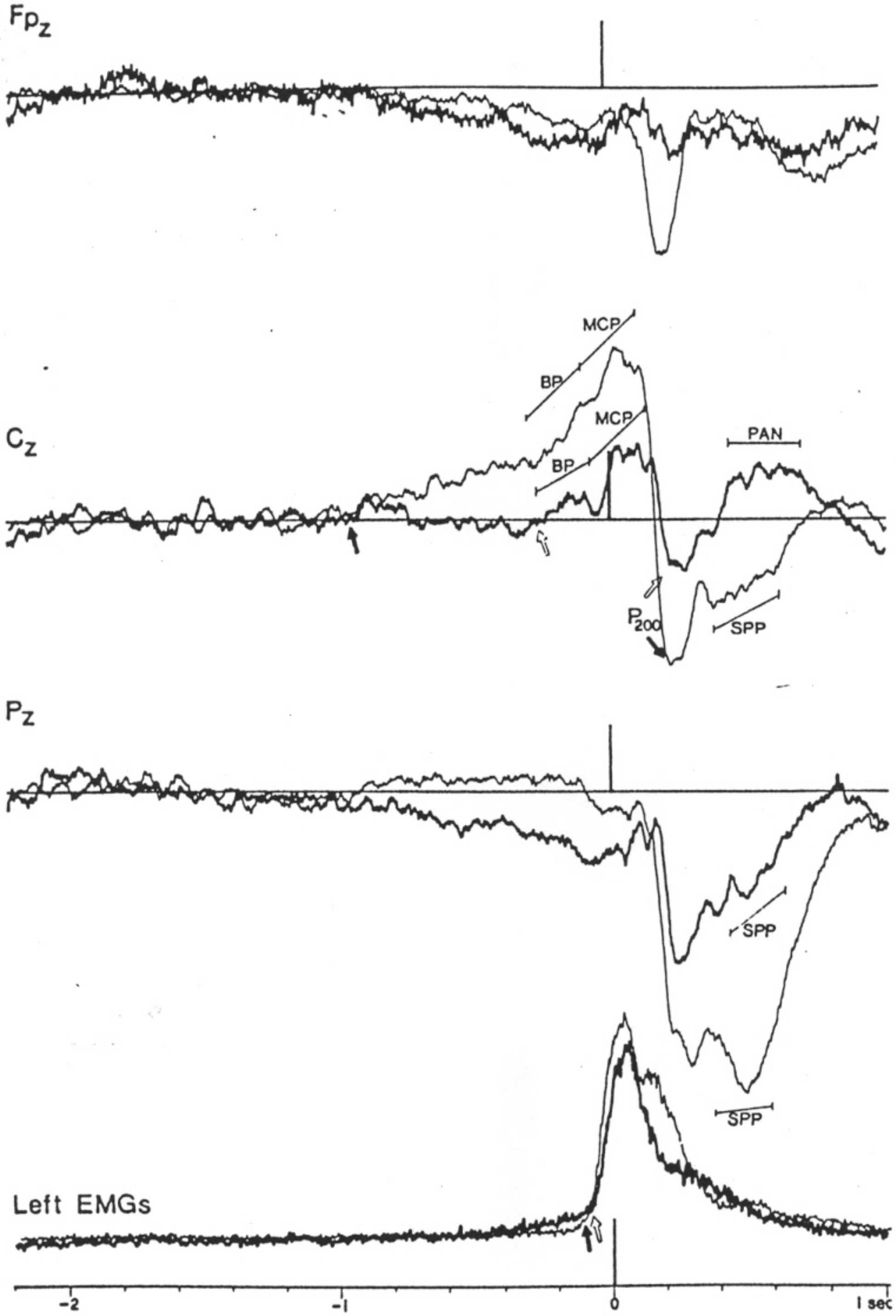

Figure 4. Grand-average movement related brain macropotentials from normal children (thin trace) and dyslexic-dysgraphic children (thick trace). 200 ms measurements periods are indicated above the Pz traces. Arrows (black for normal, white for dyslexic-dysgraphic children) indicate BP onset and offset, as measured, and EMG onset. Calibration bar for the EMGs is -12 μV.

It can be assumed that reading disorders result from the defective integration and dysfunction of numerous processes which occur at different levels and times. BP of children with the developmental reading disorders has smaller amplitude and reduced onset. N100 wave increases in latency in various cerebral areas. P200 amplitude is smaller in all cerebral areas, as are also SPP amplitude in the parietal, and PAN amplitude in the frontal, central and precentral areas. Current data in children with learning disabilities seem to indicate that during the motor-perceptual action, systems involved in the planning and programming of the efficient strategies are inadequate, and, furthermore, those involved in checking and correcting the errors are less efficient. These systems may be altered as such, may reflect deficiencies in those subsystems involved in the sensory information processing, or they may be potentially adequate, but not fully developed (Chiarenza 1989). Whether the cause is a lag or lack of maturation, is still not known. These theories have been put forward to explain the pathogenesis of specific learning disabilities (Galaburda 1988; Hynd and Semrud-Clikeman 1989).

What we know for certain is that mental deficiency in Down's syndrome is of structural origin. For this reason, we compared MBRMs of young adults with Down's syndrome and two other groups of subjects, one of the same chronologic age and the other of the same mental age. Numbers obtained for the target performances in the three groups unambiguously show that patients with Down's syndrome have neither BP nor motor cortex potential. However, SPP could be detected from various brain areas, although with a smaller amplitude (Chiarenza et al. 1985b).

Patients with Down's syndrome are known to age precociously and Alzheimer's type of tangles are observed in the frontal and precentral cortex (Ball and Nuttal 1980). We also know that MCP is the only potential which decreases in amplitude after the age of 65 (Papakostopoulos and Banerji 1980). Patients with Down's syndrome, besides having few or no preparation processes, lack the ability to process the response-generated sensory reafferent information. These subjects are known to be very slow in carrying out motor perceptive tasks (Frith and Frith 1974) and, like old people, they do not learn new motor ability tasks rapidly. Lack of MCP may be considered as a contributing factor.

In the psychiatric field, schizophrenia is, using cognitive brain potentials, certainly the most intensely studied disease. One of the most important aspects of the disease is disorganization of thought. Schizophrenic subjects appear to lack goal-directed behaviour and are characterized by both performance variability and unpredictability. In a study of chronic schizophrenic subjects deprived of drugs for at least three months, compared with a group of normal subjects matched by age, sex and socio-economic conditions, it was observed that performances and MRBMs were variously affected. Performances of the schizophrenic subjects were poorer than those of normals: smaller numbers of target performances were obtained which did not improve with the exercise, and lesser accuracy and greater variability in the performance times, which were also longer, were noted. In parallel with performance, BPs and MCPs were greatly reduced in amplitude in the frontal and precentral regions, SPP was absent from these areas and present but of markedly reduced amplitude in the parietal regions. These abnormalities could be explained as multidimensional biopsychological deficits: disturbed performance may result from the impairment in developing appropriate changes of preparation set, from defective inhibition of sensory information and from the reduced utilization of the outcome data (Chiarenza et al. 1985a).

In the field of neurology, Parkinson's disease has aroused most interest, as movement impairment is the main symptom in this disease. However, the results of various MRBM studies are contradictory. In the early studies conducted by Deecke et al. (1977) and Shibasaki et al. (1978) an abnormally small BP was found. Because of the difficulties in aligning EMG onset with the corresponding electrical brain activity, these studies have recently been criticised by Barrett et al. (1985, 1986).

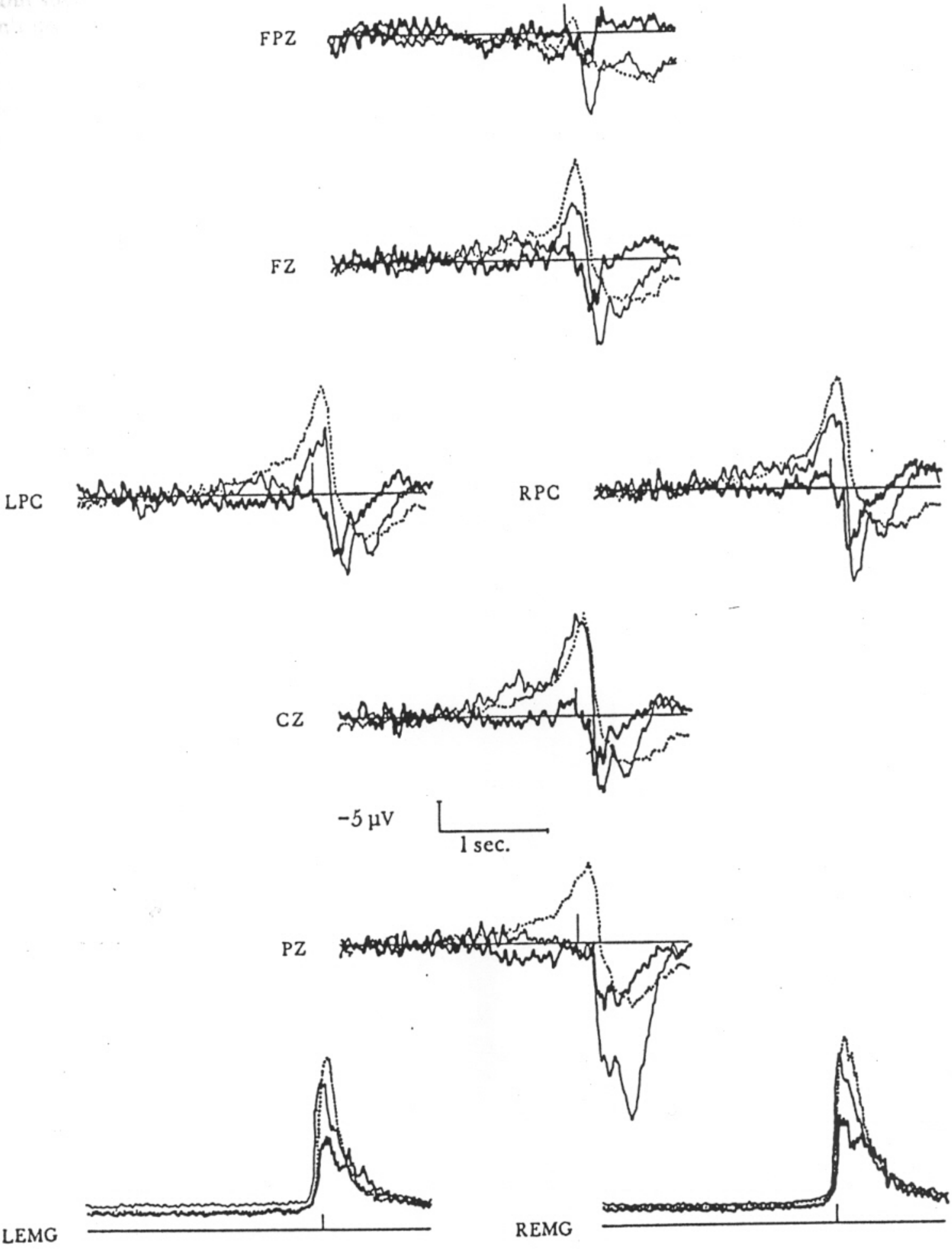

Figure 5. Grand-average movement related brain macropotentials from subjects with Down's Syndrome (thick line), and two control groups: one of the same chronological age (thin line) and the other of the same mental age (dotted line).

In addition, other methodologic difficulties exist. Some caution is therefore required in carrying out such studies. The selection of patients seems to be particularly important, as Parkinson's disease is a progressive one. Control subjects of different ages are required. In some patients akinesia while in the others tremor or rigidity may dominate. Duration of the disease and duration of therapy ought to be considered, then also the type of therapy and type of the paradigm used to record MRBMs. Up to now, a number of such studies using unskilled tasks have been conducted. These tasks by themselves produce smaller MRBM responses which are supposed to be additionally diminished in Parkinson's disease. It is therefore particularly difficult to detect changes in these subjects. Finally, it has been reported that in the subjects with discontinuation of treatment for 12 hours, the early BP component shows smaller amplitude in comparison to normal subjects (Dick et al. 1989). This component, according to Boschert and Deecke (1986), is thought to reflect activity of the supplementary motor area, whilst the late component does not appear to be affected by Parkinson's disease (Dick et al. 1989). In my opinion, it is difficult to discuss different BP components until thorough experiments are conducted in order to differentiate between them and understand their physiologic significance. Papakostopoulos et al. (1985) were using skilled tasks and were able to discriminate (on the basis of the BP amplitude), between three subgroups of patients with different symptoms and with different responses to drug treatment: 1) small BP amplitude: symptoms dominated by rigidity, good response to the drug treatment; 2) normal BP amplitude: symptoms dominated by tremor, poor response to treatment; 3) increased BP amplitude: symptoms dominated by akinesia, very good response to treatment. These findings may be relevant for the decision of which drug or a combination of drugs should be used.

I hope that this review has emphasized the importance of studying the organization of movement through the interactive, self-paced, goal-directed tasks, as well as their clinical importance. Numerous physiological processes involved in motor action are variously affected by different diseases processes (children with functional or structural learning disorders, schizophrenic or parkinsonian patients). In all these subjects it clearly emerges that poor or absent ability of planning leads to bad performance; also the knowledge of one's own actions appears to be defective. In 1980, cognitive psychologist Fischer stated that "there is no separation between thought and action, since thought is literally built from sensory-motor skills". Actually, this point of view dates back much longer time, to the 6th century B.C., when the Greek philosopher Anaxagoras stated that "man is the most intelligent living being, since it has hands".

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