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Goal or near miss! Movement potential differences between adults and children in skilled performance

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In this study, the performances and the movement-related brain macropotentials of a group of adults and 10-year-old children were analyzed to test whether and how they were correlated to the success or failure in the performance. Bereitschaftspotential (BP), motor cortex potential (MCP) and skilled performance positivity (SPP) related to preparation, execution and evaluation of performance respectively showed a significant relationship to the performance outcome. The BP area in the left precentral decreased significantly with increasing performance time. The amplitude of the MCP was maximum during target performances and decreased with increasing range of error of performance. There was a difference in trend between adults and children in the SPP latency. During target performances, SPP latency in Pz was maximum in children and minimum in adults. In children, the SPP amplitude was greater in frontal and precentral areas during target performance and decreased with increasing inaccuracy of performance. This trend was not evident in adults. The results seem to indicate that the SPP latency does not seem to depend on the performance time but on the evaluation of information conveyed by the stimulus. How this evaluation takes place seems to be different in children and adults; this evaluation process is also reflected in the SPP amplitude of children during target performances. For the adults who have already developed formal thinking, the probability that any outcome is possible exists and so the significant relationship between SPP amplitude and performance is not seen.

INTRODUCTION

In recent years it has been shown that certain types of psychomotor activity are correlated with a consistent pattern of brain electrical activity. In particular, when a subject is engaged in a motor-perceptual task in order to achieve a pre-set goal and receives real-time information about the quality of his performance, a characteristic sequence of brain macropotentials can be recorded from the scalp both in adults (Papakostopoulos, 1978a) and in children (Chiarenza et al., 1983). The task consisted in initiating the sweep of an oscilloscope with a self-paced left thumb movement and in terminating it, with the other hand, within a specific target interval time, i.e. after 40–60 ms from its initiation (Papakostopoulos, 1978a). The performances during this time interval are defined as "target performance", while those out of this interval "wrong performance" (Chiarenza et al., 1985). The brain potentials associated with this task are: the bereitschaftpotential (BP), believed to reflect the preparatory activity to movement (Kornhuber and Deecke, 1965; Vaughan et al., 1968), the motor cortex potential (MCP), proposed as an index of reafferent peripheral activity (Papakostopoulos et al., 1975) and the skilled performance positivity (SPP) related to the evaluation or knowledge of results by the subjects (Papakostopoulos, 1978a, 1978b, 1980; Papakostopoulos et al., 1986). These potentials were defined

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as movement-related brain macropotentials (MRBMs) (Papakostopoulos, 1978b).

In a study on the developmental features of the MRBMs in children aged 8–14 years, it has been observed that the percentage of target performance improves with age and each one of the MRBMs shows a different developmental pattern. Furthermore, some of these potentials are significantly correlated with performances, being the MCP of greater amplitude during target performances (Chiarenza et al., 1983).

The aim of this study is to analyze in greater detail the correlations between target and wrong performance and the MRBMs in a group of children and adults. Since the theories of cognitive development affirm that the intellectual growth goes through several stages during which action, perception, concrete or abstract thinking abilities hold in turn the dominant role, we have hypothesized that differences should have been found between adults and children both on performances and MRBMs. In particular, since abstract and probabilistic thought is typical of adults, we have also hypothesized that the SPP, potentially related to evaluation of results, should have been different in the two groups depending on the success or failure in the performance.

MATERIALS AND METHODS

Subjects

The group of children consisted of seventeen 10-year-old children (mean age: 126.41 months, S.D.: 4.06) coming from an elementary school of Milan and indicated by the teachers as normal children on the basis of their academic achievements. Furthermore, the following tests were administered to all children: Wechsler (1976), Culture Fair Scale 2 Form A (Cattell, 1951) and Bender's visual motor gestalt (Koppitz, 1964). The results were within the normal range. The adult group of 9 subjects were medical students and hospital staff, between the ages of 18 and 48 years (mean age: 348.22 months, S.D.: 121.1). All children and adults were male, right-handed, free from neurological deficits and personality disturbances, and had normal sight and hearing.

The skilled motor perceptual task (SMPT)

The subjects sat in a comfortable chair facing the 10-cm screen of a cathode ray tube (CRT) at a distance of 70 cm. A button fitted into a special hand-grip was held in each hand. The travel of the button was 5 mm. The task consisted in starting a sweep of the oscilloscope trace with the left thumb and in stopping it in a predetermined area of the oscilloscope by pushing the other button with the right thumb; the sweep velocity was 1 mm/ms; the target area corresponded to a time interval between 40 and 60 ms.

After a verbal explanation of the task, to ensure that all subjects have understood the verbal instructions, the experimenter carried out a few trials and the subjects had to indicate the performance results; subsequently, so that all subjects could start from the same training level, they were allowed a short practice period. The recording procedure was initiated only after all subjects were able to stop the oscilloscope sweep at least twice in the 40–60 ms interval. This practice was also necessary to enable the subjects to become familiar with controlling eye-movements or blinking during the execution of the task and to keep an interval of 7–20 s between any two attempts. The subjects were also asked to remain relaxed during the task and avoid muscular preparatory movements before pressing.

Recording procedure

Ag/AgCl electrodes were placed at Fpz, Fz, Cz, Pz and right (RPC) and left (LPC) precentral areas. Each electrode was referred to linked mastoid electrodes. The EOG was recorded bipolarly using an electrode above and below the right eye to monitor blinking and eye movements; trials with artifacts were excluded. The surface EMG was recorded from the left and right forearm flexor muscles. The impedance of the electrodes was less than 3 kΩ. The time constant and high-frequency response (−3 dB) was 8 s and 30 Hz for the EEG, and 0.03 s and 1.6 kHz for the EMG, respectively. The analysis started with sampling for each channel, a square wave of ± 25 μV for calibration purposes. During the on-line analysis, on reception of the trigger pulse obtained from an electric pulse generated at the press of the left-hand button, 3.2 s for each channel were sampled at a rate of 250 Hz. Of these, 2.2 s preceded the trigger pulse and 1 s 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 detected and stored on disc. The recording ended after 100 artifact-free trials were collected.

Data measurements

Performances. The time interval between the two presses is measured and defined as 'performance time'. The number of performances reaching the target interval (i.e. 40–60 ms) was measured and defined 'target performance'. The number of performances shorter than 40 ms and longer than 60 ms was also counted and defined 'wrong performance'.

EMGs and MRBMs measurements. Each performance during SMPT was allocated to one of the 5 intervals (interval 1: 0–20 ms; interval 2: 21–39 ms; interval 3: 40–60 ms; interval 4: 61–79 ms; interval 5: 80–99 ms) and separate averages for each interval were computed (Chiarenza et al., 1982a). Obviously the number of trials for each interval and for each subject varied slightly. However, there was no instance of n less than 11 and this number of trials was adequate to have a good signal-to-noise ratio.

The mean amplitude of the EMG prior to movement, the peak amplitude during movement and the EMG rise time of the rectified surface left and right electromyograms were calculated after locating the EMG onset and the EMG peak. The MRBMs were measured as follows: the area of BP was measured from the BP onset to the point corresponding to that of the EMG onset; MCP amplitude was taken as the average over the 200 ms immediately following EMG onset and was measured as the difference from the BP mean amplitude measured for a 200-ms period immediately preceding EMG onset; SPP amplitude was taken as the average value over 200 ms centred on the main positive (SPP) peak value in the latency band between 350 and 650 ms from the left-hand trigger. This value was measured from the baseline. SPP latencies were measured from the left-hand trigger pulse.

Statistical analysis

First of all we tested whether there were age-related differences in the performances and MRBMs between adults and children. For this reason the same type of statistical analysis described in the developmental paper of the MRBMs (Chiarenza et al., 1983), that is variance analysis by means of multiple linear regression was used. Furthermore, in order to test, not only for an age effect, but whether there was an effect dependent on the outcome of the performance (positive or negative), we elected as the independent variable the means of the performance in the time intervals described above and as the dependent variable the measurements of the various MRBMs and EMGs. On these data polynomial regression of second order was applied to evaluate whether this model could describe adequately the trend of the potentials related to the performance. Regression analysis allowed evaluating the goodness of fit by means of tests of significance. The significance of the polynomial regression was evaluated by means of F-value and the significance of the individual regression coefficients by means of t-values. The signs of the regression coefficients revealed the trend of the parabola.

The childrens' and adults' data were processed separately and then combined. Regression analysis was done separately on the EMG and EEG data. Furthermore, multile linear regression analysis was done for each time interval to assess the effect of age on the number and average values of the performance.

RESULTS

All the subjects understood the verbal explanation of the task and after a brief training were able to complete the task.

Performance

Table I shows the number of performances and the mean of performance time in each time interval for children and adults. Adults and children

TABLE I

Number of performances and mean performance time of all the adults (A) and the children (C) in each of the 5 time intervals

		Intervals									
		1		*2*		*3*		*4*		*5*	
		A	*C*	*A*	*C*	*A*	*C*	*A*	*C*	*A*	*C*
Number of performances	X	9.86	8.71	20.44	12.06	32.00	28.59	22.89	22.82	10.11	12.82
	S.D.	8.49	8.87	13.74	7.13	8.83	7.48	15.00	8.89	5.88	5.34
Mean performance time	X	16.53	12.58	32.10	31.08	49.73	50.70	69.52	70.40	88.11	90.37
	S.D.	0.83	3.22	2.32	1.68	1.55	1.75	1.73	1.28	2.98	1.70

totalled practically the same number of target performances (interval 3: $t = 1.26$; $P =$ n.s.), although the adults were more accurate since they had a greater number of wrong performance around the target. Multiple linear regression analysis of variance showed that the number of performances for adults in interval 2 was significantly greater than that for children ($t = 2.51$; $P < 0.05$). The adults had a higher mean value of performance in interval 1 than the children ($t = 3.07$; $P < 0.01$). There was no statistically significant differences for the number of wrong performances in interval 4 ($t = 0.16$; $P =$ n.s.) and interval 5 ($t = -1.44$; $P =$ n.s.). The multiple linear regression showed that while wrong performances with values below 40 ms were increasing with age ($t = 3.32$; $P < 0.01$), those with values above 60 ms showed the reverse trend ($t = -3.56$; $P < 0.01$).

Electromyograms

The electromyographic function evaluated through EMG rise time, EMG base amplitude and EMG peak amplitude, was related significantly to age and not to performance. Both the base EMG amplitude ($t = 2.09$; $P < 0.05$) and EMG rise-time ($t = 3.34$; $P < 0.01$) decreased with age, while the peak amplitude increased ($t = 3.71$; $P < 0.01$).

MRBMs

Neither adult nor child basic MRBM patterns changed when, instead of averaging the trials according to their order of execution, selected trials with similar performances were averaged. BP, MCP and SPP potentials showed a significant relationship to age and performances.

BP

The area of BP increased significantly with age in all the brain areas recorded except Fpz. (Fpz: $t = 0.21$, $P =$ n.s.; Fz: $t = 3.46$, $P < 0.01$; Cz: $t = -4.65$, $P < 0.01$; Pz: $t = -5.80$, $P < 0.01$; RPC: $t = 5.28$, $P < 0.01$; LPC: $t = -6.58$, $P < 0.01$). Regression analysis showed that the BP area both

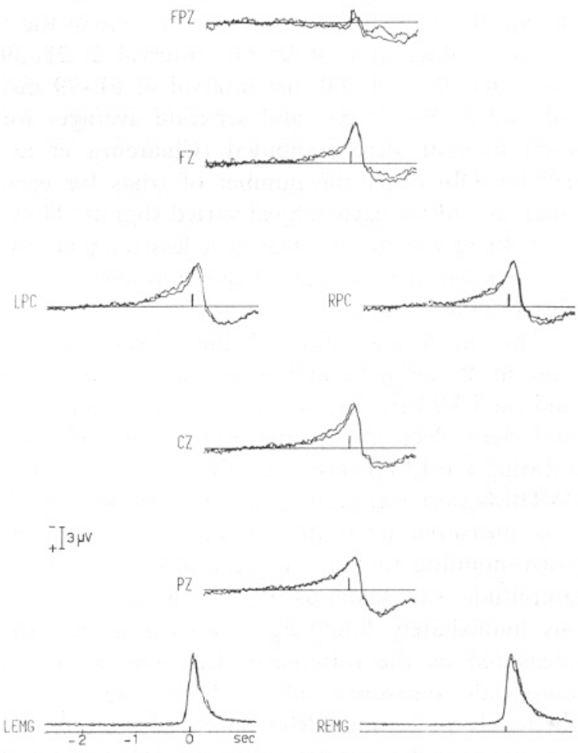

Fig. 1. Superimposed grand-averages of MRBMs and rectified EMGs of adults during target performance and wrong performance of interval 2. Note the presence of SPP in all locations during both target performance and wrong performance.

in adult and child in the left-precentral lead derivation significantly decreased with increasing performance time ($t = -2.31$; $P < 0.05$).

MCP

The amplitude of the MCP increased significantly with age in all locations recorded (Fpz: $t = -5.21$, $P < 0.01$; Fz: $t = -5.20$, $P < 0.01$; Cz: $t = -2.51$, $P < 0.05$; Pz: $t = -7.77$, $P < 0.01$; RPC: $t = -3.64$, $P < 0.01$; LPC: $t = -3.22$, $P < 0.01$). In all the brain areas recorded, except FPz and Pz, the amplitude of the MCP was maximum during target performance and decreased with increasing range of error of performance. (Fpz: $t = 0.52$, $P =$ n.s.; Fz: $t = 2.70$, $P < 0.01$; Cz: $t = 2.76$, $P < 0.01$; Pz: $t = 1.45$, $P =$ n.s.; RPC: $t = 2.79$, $P < 0.01$; LPC: $t = 2.65$, $P < 0.01$).

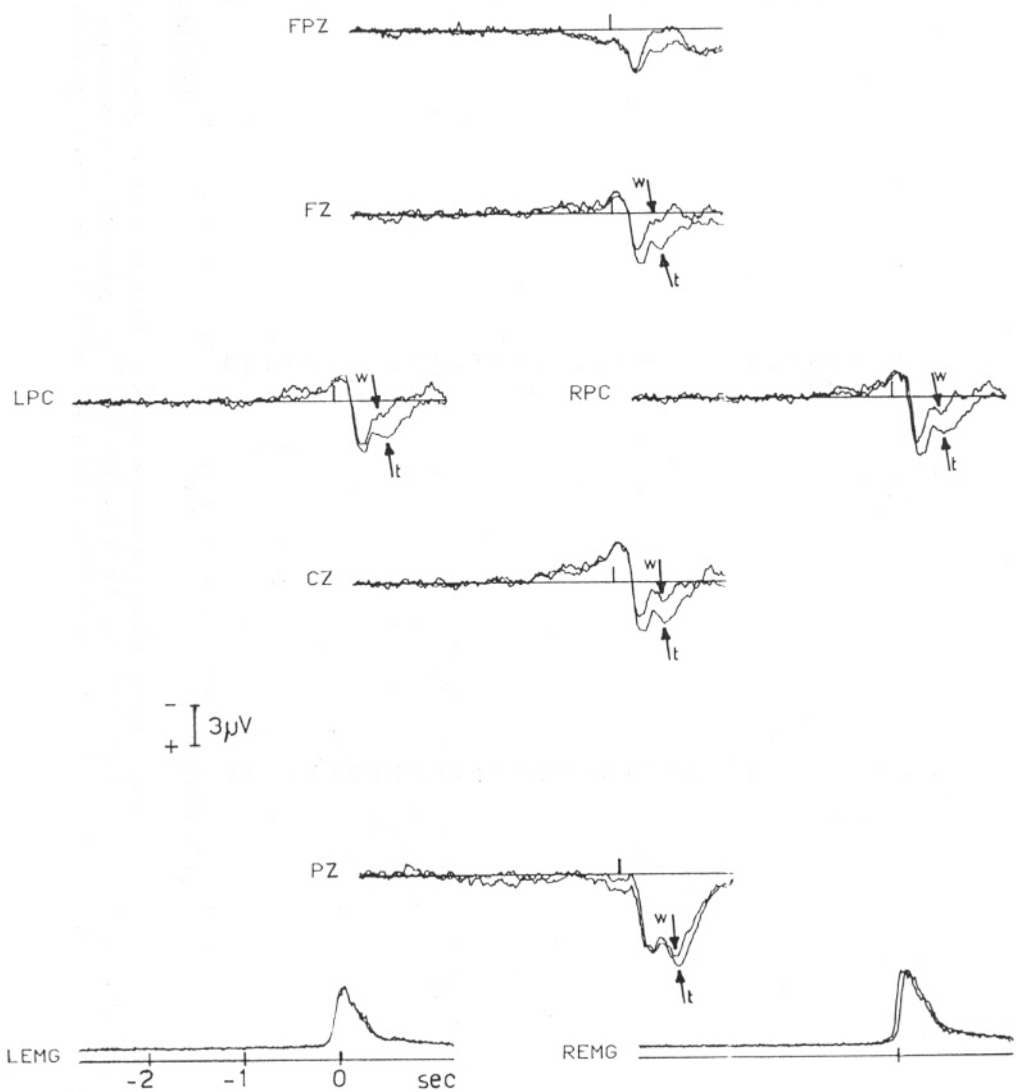

Fig. 2. Superimposed grand-averages of MRBMs and rectified EMGs of children during target performance (t) and wrong performance (w) of the interval 2. Note the consistent reduction of the SPP amplitude with wrong performance in the frontal and precentral areas compared to the parietal areas.

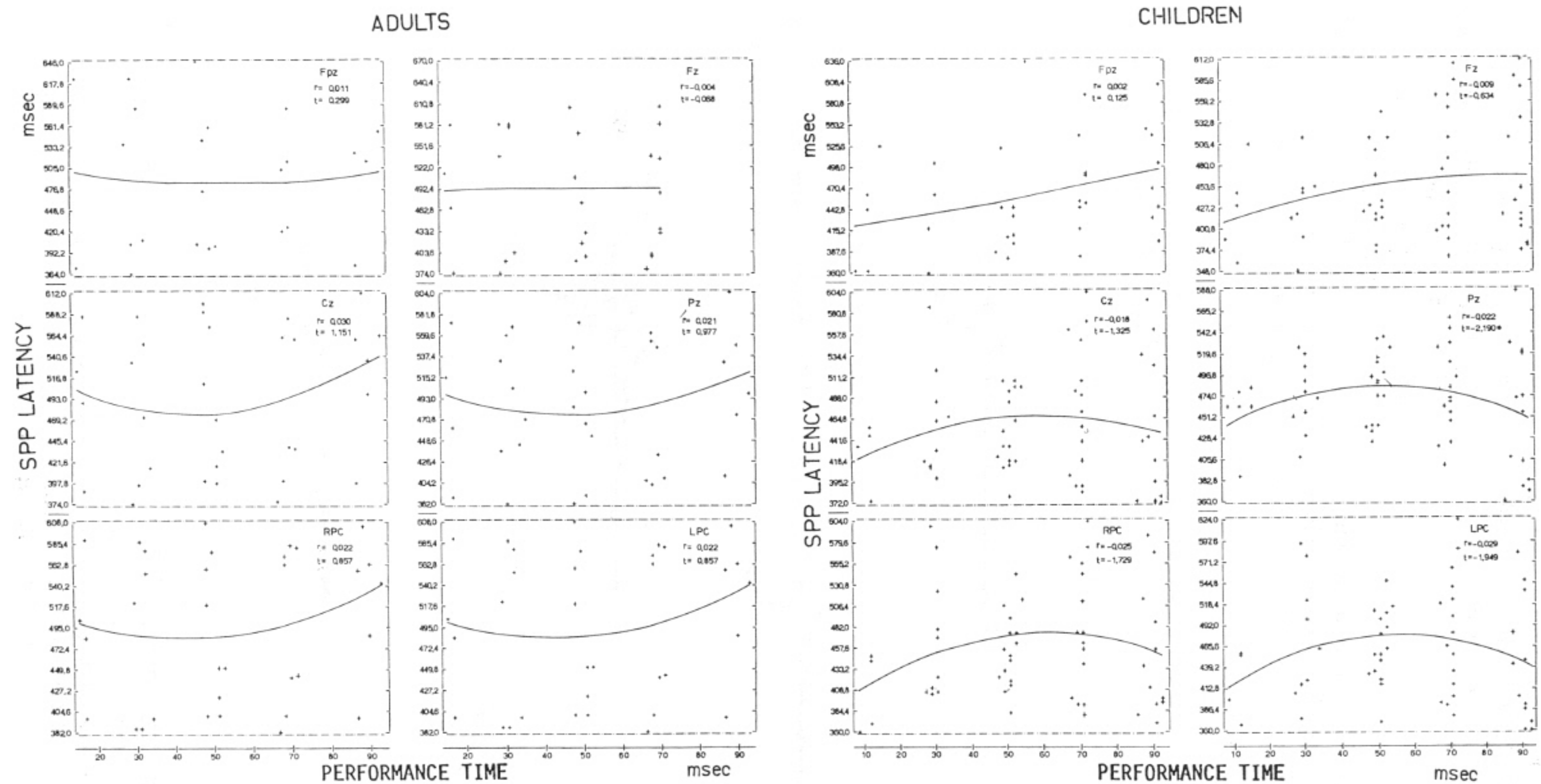

Fig. 3. The latency values of SPP of all the groups of children and adults are shown in relation to the performance time in the 5 time intervals. In this figure the continuous line represents the trend of SPP parameters related to performance time as it is generated from the polynomial regression. For each line the r-value represents the regression coefficient of the second degree term and the t-value its statistical significance (* $P < 0.05$).

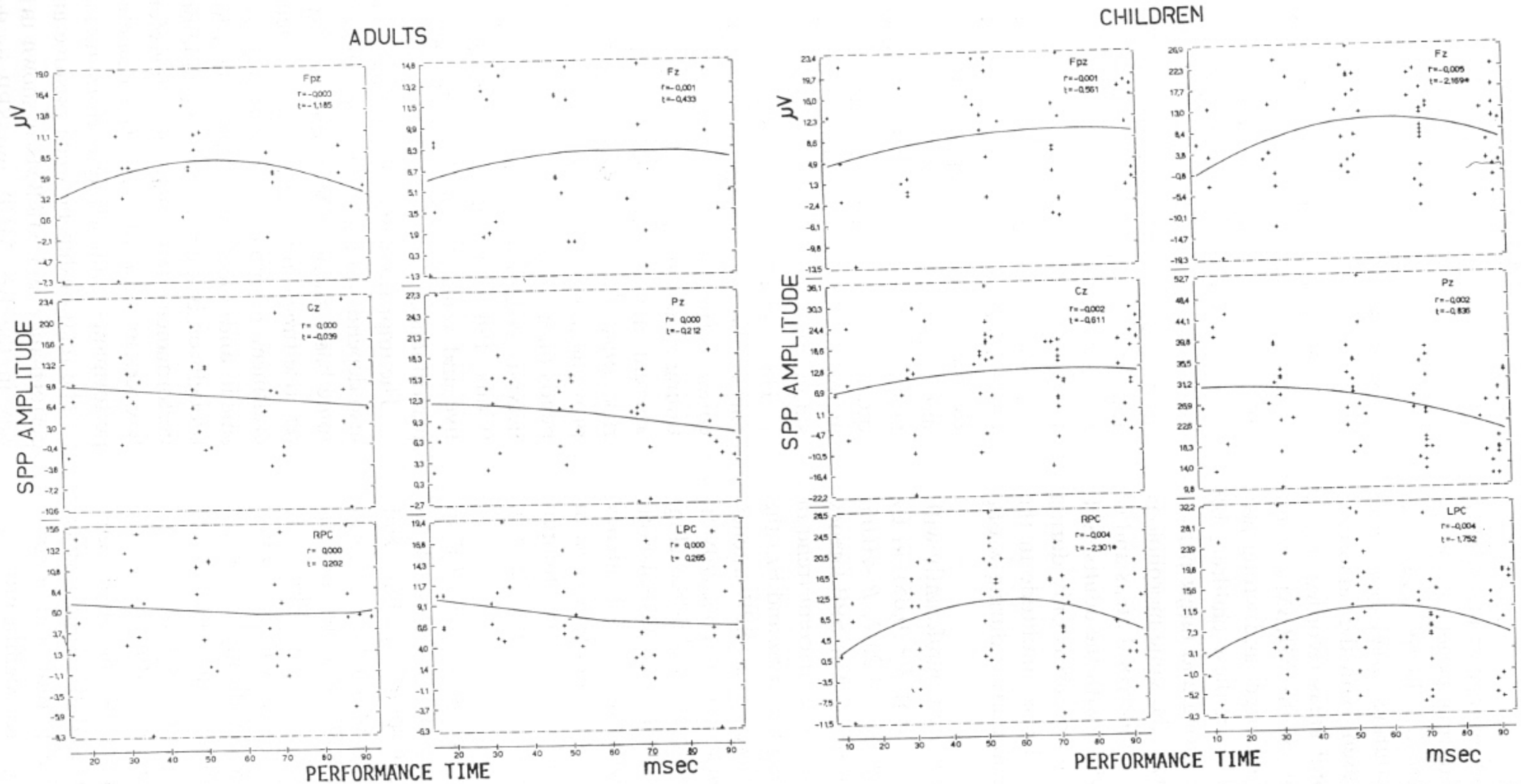

Fig. 4. The amplitude values of SPP of all the groups of children and adults are shown in relation to the performance time in the 5 time intervals. In this figure the continuous line represents the trend of SPP parameters related to performance time as it is generated from the polynomial regression. For each line the *r*-value represents the regression coefficient of the second degree term and the *t*-value its statistical significance (* $P < 0.05$).

SPP

Fig. 1 shows the grand average of the MRBMs of the group of adults during target and wrong performance of the interval 2. In the adults, the BP, MCP, SPP – both during target and wrong performances – were present with the same morphology in all the cerebral areas recorded. Fig. 2 shows the grand average of the MRBMs of the 10-year-old children during target and wrong performance of the interval 2. In these children, BP and MCP – both during wrong and target performances – were present with the same morphology on the central and precentral cerebral areas and of less amplitude in comparison with the adults. SPP was present on all the cerebral areas only during target performances and of less amplitude in the frontal, central and precentral areas during wrong performances.

The latency of SPP decreased significantly with increasing age in Fz ($t = -2.35$; $P < 0.05$), in Cz ($t = -2.30$; $P < 0.05$), RPC ($t = -2.07$; $P < 0.05$) and LPC ($t = -2.04$; $P < 0.05$). The SPP latency related to the performance had a different trend in adults and in children. Except for Fpz and Fz, the polynomial regression showed that SPP latency had a parabolic trend with upward concavity in adults and downward concavity in children (Fig. 3). The peak of the parabola was reached in both groups during the target performance; SPP latency in Pz was maximum in children and minimum in adults. This trend in Pz in the group of children was statistically significant ($r = -0.022$; $t = -2.19$; $P < 0.05$).

Even in respect of the amplitude of SPP in relation to the performances the polynomial regression showed a different trend in adults and children (Fig. 4). A significant relationship was shown by the frontal and RPC areas in children (Fz: $r = -0.005$; $t = -2.17$; $P < 0.05$; RPC: $r = -0.004$, $t = 2.30$ $P < 0.05$). Both in Fz and RPC, the SPP amplitude was greater during the target performance and decreased with increasing inaccuracy of performance. In Cz and Pz there was no significant relationship between SPP amplitude and performance time. There was no significant systematic relationship in the adults in the various brain areas between SPP amplitude and performance time. The increasing age significantly reduced the amplitude of SPP only in Pz ($t = -9.56$; $P < 0.001$).

DISCUSSION

The principal difference between adults and children in the performance of the SMPT is that the former are more accurate. The adults had a greater number of wrong performances around the target. The average value for performances in the first interval is also higher for adults. As age increases, the number of performances below 40 ms tends to increase, while those slower than 60 ms decrease.

These differences cannot be attributed to misunderstanding of the verbal instructions, a different training level or lack of commitment in performing the task as all the subjects carried out the task correctly respecting the bimanual motor sequence, had had equal opportunity to practice and at the end of the task expressed their satisfaction stating that they had done their best.

These data seem to support the hypothesis that part of the preparation for a movement sequence entails setting a central clock which controls the timing of the sequence and is linked to different afferent and efferent modalities (Hirsch and Sterrick, 1964; Rosenbaum and Patashnik, 1980). Improvement in the performance of this clock depends on greater synaptic efficiency of the central nervous system, which comes with increasing age (Craik, 1947), and on the presence of proprioceptive and visual feedback on the accuracy of the performance.

The improvement in electromyographic activity also depends on age. The adults show lower EMG tonic base, greater EMG peak amplitude and faster rise-time, indicating better synchronized recruitment of motor units (Basmajian, 1963; Desmedt and Godaux, 1978). The EMG changes brought on by age lead to general improvement in performance and there are therefore no differences in the EMG activity parameters of target performances and wrong performances.

The relationship between positive and negative performance and MRBMs is shown in a different way in the BP, MCP and SPP in the different brain areas. There is evidence from previous research that BP increases in amplitude both in adults and children in going from the unskilled to the skilled condition (Papakostopoulos, 1978b; Chiarenza et al., 1980) and has already been proposed as an electrophysiological indicator of cerebral efficiency during the preparatory period. The increase in BP amplitude in all subjects during the wrong performance from 0 to 39 ms might be explained as 'non-optimal' increased cortical synchronization which produces faster responses. Consequently, the BP associated with longer performances has a lower amplitude as previously reported in adults (Papakostopoulos, 1978b) and in children with learning disabilities (Chiarenza et al., 1982b). The observation that this BP trend associated with the performance is significant only in the left precentral region is in agreement with the fact that all the subjects were right-handed and with previous reports of lateralization of BP during unimanual and bimanual skilled or unskilled actions (Papakostopoulos, 1980b; Kristeva and Deecke, 1980).

MCP shows a different trend to BP, with maximum amplitude both in adults and children during target performances and decreasing with increasing range of error. This significant relationship between MCP and performance in the frontal, central and precentral areas could reflect increased cortical response to peripheral input or some selective facilitation or disinhibition of a subcortical filtering mechanism regulating sensory input during the most correct performance.

Unlike the BP and MCP, both the latency and amplitude of SPP are different in adults and children. The parabolic trend of the SPP latency at Pz peaks in children during target performances, while in adults it peaks during wrong performances. The difference in SPP latencies between adults and children cannot be attributed to the different number of 'wins' because they both have almost the same number of target performance events. The SPP latency does not seem to depend on the performance time, but on the time needed to evaluate the information conveyed by the stimulus. How this evaluation takes place seems to be different in children and adults. The adults, who have higher SPP latencies when they have to evaluate an incorrect performance, both faster and slower, seem to deliberate on the reason for the error and consider changing strategy. This behaviour is not seen in children: SPP latency is maximum only during target performances and decreases with increasing range of error. It seems that they give weight only to the sought-after, desired event: victory. They do not reconsider failed attempts but pass on immediately to the next attempt.

The importance the children give to winning is also reflected in the amplitude of the SPP. In children, the amplitude of SPP is maximum in all cerebral areas recorded during target performances wich had a frequency of 30%, and decreases with increasing error. In both faster and slower wrong performances the amplitude decreases significantly in the frontal and RPC areas. From the interviews conducted after the recording, it emerged that the attitude of the children towards the task was similar to that shown in a P300 experiment in which the target performance is the relevant and rare event and the wrong performance the irrelevant and frequent (see Johnson, 1986, for an updated review and model of P300). In the adults there was no relationship between the quality of performance and the SPP amplitude. SPP was present with the same amplitude in all brain areas, both during target performances and wrong performances even though the former had a frequency of only 32%. Adults seemed to give equal relevance to both events. It is important to stress that the SPP amplitude in the parietal areas both in adults and children does not change with the qualitative probability of the results, as though SPP indicated only the registration of an event perceived. However, further studies are necessary to evaluate the similarities and the differences of these two positive potentials related to the outcome of the performance.

It is also interesting to note how a positive potential such as SPP that is present in all the areas can behave so differently on the frontal, precentral and parietal areas in adults and children depending on the results of the performances. Our data suggest that there is a difference in the nature and organization of information processing reflected by the behaviour of the MRBMs, although these potentials can develop in the same cortical domain. The present data seem to give some support to some theoretical proposal put some years ago by Papakostopoulos (1978c) proposing that the factors which modulate and determine the value of a determined response in a given cortical domain, depend on past, present or anticipated future input/output of the domain. Particularly areas may have many, few or no factors in common with other areas. If there are common factors they may vary in unison or with varying degree of independence in the different domain. It seems that sensorimotor processes and cognitive processes are closely related and can procede within the same cortical domain.

Developmental cognitive theories start from the postulate that the motor action is the source of mental operations (Bruner, 1970; Fischer, 1980; Piaget, 1954, 1957). The subject's actions are crucial in making him acquire ideas or strategies, with which he will successfully interact with the environment. According to those theories the age of ten years is the boundary between the concrete operations period and the adult capacity for abstract and probabilistic thought. Before the age of ten, children are orientated towards concrete things and events in the immediate present, so movement towards the non-present or potential is limited. For adults, who have developed the capacity for abstract and formal thought, the probability that any outcome is possible exists: the adult lives in the world of the possible and hypothetical.

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