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Learning during visual search in children with attentional and learning problems: A trial-to-trial evaluation of RT and ERP measures

J. C. Woestenburg, E. A. Das-Smaal, E. Brand, and S. Kramer

Department of Psychonomy, Free University, Amsterdam, The Netherlands

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ABSTRACT Trial to trial Event Related Potentials (ERPs) were recorded from children with attentional problems (APs), learning problems (LPs), and from children without these problems (NCs).The task required the subjects to memorize two figures and to selectively respond to their occurrence in a series of stimuli. Stimuli consisted of a display of figures at eight locations in a circle, whereby the targets were presented at a random or a fixed location. Learning from knowledge of prior displays was possible only in the fixed condition. Learning during presentation of the fixed series was manifest in several components. A Slow Wave (SW) difference between series, initially not present, developed within seven trials, and thus corresponded to the rapidity with which the reaction times (RTs) decreased over trials. A larger occipital SW difference was discovered in AP children and a larger fronto-central one in LP children compared to normals. The latency of this SW and the P300 difference between series were delayed with about 200 msec in APs compared to NCs. The task difference in the earliest component, the P120, that increased after behavioral task acquisition was completed, was seen in normal children only. This probably reflected feature-specific (location) attentional demands, that decreased slowly in normal children when the task became more predictable following a number of trials. Task differences of the N200, possibly reflecting covert orienting of attention, were initially smaller in APs and LPs than those of NCs, but they increased in APs (and in LPs more slowly) over trials. Differences were found for parietal amplitudes of the P300 in LPs and NCs, but not for APs. We concluded that AP children show early deficits that could orginate from a limited capacity in focussing attention, which in turn prolongs stimulus evaluation. All subsequent processes are delayed by a similar amount of time. In addition, the relatively small fronto-central ERP's of the AP group suggest diminished frontal functioning. Problems in task acquisition and a prolonged process of memory updating might be induced by the slow adaptation to task differences in LP's, and delayed parietal SWs during task acquisition together with a marked fronto-central distribution and no RT difference.

Introduction

Attention is known to have an influence on the efficiency of cognitive functioning. In fact, attention is a fundamental prerequisite for learning, and more serious forms of attention deficits are often associated with learning disorders (Cantwell & Satterfield, 1978). Children whose primary complaint is poor learning also have attentional problems (Ackerman, Dykman & Oglesby, 1983). Large scale assessment studies in various countries point to a considerable incidence of attention problems at elementary schools within the range of 6 to 12 years (e.g., Achenbach, Verhulst, Edelbrock, Baron, & Akkerhuis, 1987). However, these reports rely on teachers' ratings, and laboratory studies are scarce. But some of the attentional problems among elementary school children may be related to those occurring in clinical groups. Research concerning attentional deficits has been mainly conducted in clinical groups, such as schizophrenic, hyperactive, and depressive subjects and in autistic children. The results of these studies, although not directly applicable, might provide some clues on the attentional problems among children attending elementary schools.

There is wide agreement that ERP components are smaller in clinical or subnormal groups than in normal ones (Holcomb, Ackerman & Dykman, 1985, 1986). P300 was substantially reduced in schizophrenics (Roth, Horvath, Pfefferbaum & Kopell, 1980), depressed and demented patients (Pfefferbaum, Wenegrat, Ford, Roth & Kopell, 1984), autistic subjects (Ciesielski, Courchesne & Elmasian, 1990) and in hyperactive children (Loiselle, Stamm, Maitinsky & Whipple, 1980).

Learning disabled children in general evoke deviant ERPs, but specific ERP effects for children with attentional deficit disorder (ADD) or reading disorders (RD) have not been consistently reported. Holcomb et al. (1985, 1986) reported smaller components and increased latencies for ADD children only, while RDs had smaller components to word than to symbol stimuli. Reduced amplitudes of the P300 were present for learning disabled children (Rothenberger, 1982). Harter, Anllo-Vento, Wood & Schroeder (1988) found a reduction in positivity at about 300 to 360 msec over the central region for RD children, while an increase and a different scalp distribution were evident in ADD boys. Harter, Diering and Wood (1988) did not find an amplitude reduction of P240 and P500 in children with ADD, but in RD children. Contrary to these studies, Licht, Jonkman, Bakker and Woestenburg (1989) did not find any differences in P300 amplitudes among groups of young subjects with different types of dyslexia or in normal controls.

Apart from differences in P300 there are other components which are reported to be deviant. Satterfield, Schell, Nicholas and Backs (1988) found a reduction in the auditory N2 amplitude in a selective attention task for boys with Attention Deficit Disorder with Hyperactivity (ADDH). In Minimal Brain Damaged children, Cammann (1985) discovered delayed latencies of P2 and N2 components during discrimination between visual and auditive stimuli.

These effects reflect an inadequate directing of attention, which must already occur early in the information processing sequence, and is related to both automatic and controlled processing. Unfortunately, the studies mentioned above are of a great diversity, and their results are not consistent.

One source of incompatible results might be the kind of stimuli employed in a study. In the Holcomb studies (1985, 1986) RDs had different ERP responses to words than to symbols, thus indicating an inefficient use of attentional resources with regard to word processing. Harter et al. (1988a,b), testing visuo-spatial rather than word processing capacities, found indications of enhanced attention in RD children compared to ADD, that could be associated with inefficient attention regarding word processing as found by Holcomb et al. Using auditory stimuli Satterfield et al. (1988) and Loiselle et al. (1980) found reduced selection negativity in children with ADDH.

Harter et al. (1988) advanced another explanation for the inconsistent results by emphasizing the growing evidence that reading or learning disabled children do not constitute a homogeneous group. In the *Diagnostic and Statistical Manual of Mental Disorders (DSM-III)* of the American Psychiatric Association (1980), ADD is split into two subgroups, with and without hyperactivity. Barkley (1989) specified an ADD group without hyperactive behavior and impulsive or disruptive behavior, but with a focussed attention disorder, and symptoms like day-dreaming, cognitive slowness (inconsistent memory retrieval), hypoactivity, mental confusion, and social withdrawal. According to Lahey and Carlson (1991) two factors, corresponding to the two subtypes of ADD, are consistently present: One of them is characterized by inattention and disorganization, the other by motor hyperactivity and impulsive responding. Excluding hyperactivity from a group of RD pupils does not automatically mean that hypoactivity is also excluded from all the others, and therefore it is possible that Harter's RD group was confounded with the hypoactive subgroup of ADDs, a group with a focussed attention disorder which may be associated with a reduced frontal selection negativity and reduced P360's and which may be wrongly ascribed to RD.

A series of studies on ADD subgroups with hyperactivity (Van der Meere & Sergeant, 1987, 1988a, 1988b) reported underlying deficits in the motor decision process rather than deficits in encoding or central processing. In fact, this view has been supported by research using drugs (such as methylphenidate) which reduce hyperactive behavior. This drug appears to influence reaction time, but not the latency of the P300 in hyperactive children, and possibly affects a stage that follows the central processing of stimuli (Klorman, Brumaghim, Coons, Peloquin, Strauss, Lewine, Borgstedt, & Goldstein, 1988; Klorman, Brumaghim, Firzpatrick & Borgstedt, 1987).

To summarize, there are several factors that might explain the incompatible results: Children with serious forms of attention deficits do not form a homogeneous group and the tasks consisted either of widely differing linguistic or visuo-spatial stimuli. The latter factor may be related to differences in the sensory pathways during information processing of either visuo-spatial or linguistic properties of stimuli (Conners, 1990).

The selective nature of visuo-spatial attention in normal subjects has been most extensively studied in experiments in which the spatial separation of stimulus features (that is, the letters) was rather small (Okita, Wijers, Mulder & Mulder, 1985). These findings suggest that selection is based on a conjunction of features such as location and orientation starting 200 msecs after stimulus onset. This process is followed by controlled search and decision processes. Wijers, Mulder, Okita, Mulder, and Scheffer (1988) found different effects of attention in normal subjects: an early occipital negativity around 150 msec reflecting feature specific attention, and a later central N2b (240 msec) component reflecting covert orienting of attention. Later components were associated with controlled search and target detection. The authors also found evidence for pre-attentive mechanisms, operating in parallel, and for a slower serial attentive system indexed by search negativity. Harter and Aine (1984) found that attention to visual space in the peripheral visual field led to faster responses that were more prominent in the extrastriate cortex, which is a part of the tecto-pulvinar system specialized in attending to visual space (Conners, 1990). Posner and Petersen (1990) stressed the involvement of the latter system in orienting to visual locations. Disorders in higher level cognitions could be due to these attentional deficits. If spatial attention is important in certain forms of ADD, deficits may be located in the tecto-pulvinar system (Conners, 1990; Posner & Petersen, 1990). Such an influence is best studied by using non-linguistic stimuli.

The current study focussed on visuo-spatial attention using complex non-linguistic stimuli. Visual search for complex patterns becomes slower and more attention-demanding when similarity between targets and non-targets increases (Duncan & Humphrey, 1989). The subjects consisted of children who had attentional and learning problems and attended normal elementary schools. An experimental design was employed that measures the effects of discovering regularities in trial to trial changes, as seen in Reaction Times (RTs) and ERP components during attention demanding conditions in a spatial attention task. The task required the subjects to memorize two figures and to respond selectively to their occurrence in a series of stimuli. The stimuli consisted of a display of figures on eight locations in a circle. Two search conditions were employed: (a) *a random* series, in which the target was presented at random locations on the display (requiring divided attention), and (b) a *fixed* series, in which the target was presented on the same location throughout the series (requiring focussed attention). When attention can be focussed, the amount of attention spent on relevant stimuli is high and information processing is fast. On the other hand, in the divided attention condition, attention was necessarily distributed to different locations, and subjects had to monitor or scan several inputs in search for the target. This scanning process becomes manifest in increased reaction times. In the present study subjects were not informed about the nature of the series, and thus the crucial difference between tasks was that in the fixed series the attention of the subject changed from divided to focussed during the process of discovering the fixed nature of the target position, whereas the random series remained a divided attention task as no cues became available. Cuing enables foveating a stimulus, and improves acuity, and therefore information processing (Posner & Petersen, 1990). According to Prinzmetal, Presti and Posner (1986) spatial attention facilitates feature integration, but it also facilitates the encoding of the features themselves. In other words it increases the efficiency of information processing of targets among similar-appearing non-targets. In earlier studies (Kok, Looren de Jong, Woestenburg, Logman, & van Rooy, 1987; Looren de Jong, Kok, Woestenburg, Logman & van Rooy, 1989), an increase of the P300 was measured in young subjects over trials on stimuli presented in fixed conditions.

The results showed that RTs became shorter for targets on the predictable locations. Scanning of the display was allowed because eye movement artifacts could be removed from the EEG afterwards (Van Driel, Woestenburg & van Blokland-Vogelensang, 1989; Woestenburg, Verbaten & Slangen, 1983a). A trial to trial evaluation was possible because single trial ERPs were estimated with the Orthogonal Polynomial Trend Analysis (OPTA) (Woestenburg, Verbaten, Van Hees & Slangen, 1983b) instead of classical averaging.

The same techniques were applied here. The advantage of this type of analysis is that the process of learning can be followed and analyzed more directly. The children in the present study did not belong to clinical groups, but functioned less than optimally. One group was diagnosed as having attention problems, based on both their teacher's judgements on classroom attention and the score of an attention test for which perceptual speed was an important factor. The other group was characterized as having learning problems, as indexed by tests on technical reading and arithmetic. These instruments were employed because they are commonly used and accepted by school counseling centers. Both experimental groups were compared to a control group.

We assumed that the selection of spatial locations involves processes mediated by the tecto-pulvinar path of the primary visual cortex, the posterior parietal cortex and frontal locations. We furthermore hypothesized that manifestations of spatial attention occur at posterior locations and are maximal in control subjects. We expected that children with classroom attention problems would be impaired in directing attention to complex-spatial stimuli and would show reduced amplitudes in early components in the range of 150 to 240 msec that are modulated by selection negativity (Wijers et al., 1988). These early deficits might cause delayed latencies of P300, SWs and RTs in equal amounts. Interestingly, such a decrease does not occur, or only to a much lesser extent, in children with reading problems. As both display and memory search were relevant processes in the current task, less efficient memory retrieval functions among children with learning problems compared to normal children might be manifested in later ERP components such as delays in the P300 and Slow wave.

Method

Subjects

Sixty children aged 10–11 years were selected from a pool of 179 children. All children attended normal elementary schools and also participated in a larger study on behavioral components of attention problems (Brand, in preparation). The selection was based on their scores on the following tests.

The Bourdon/Vos concentration test, a cancellation task in which each child had to detect and cross out patterns of 4 dots, was administered. The attention problem factor (AP) was based on scores in the teachers' ratings of attentional behavior in the classroom on the attention scale of the Amsterdam Behavior Questionnaire (de Jong & Das-Smaal, 1991). Scores on a test of arithmetic, selected from the Wide Range Achievement Test (WRAT), and on the BRUS test for technical reading of words, formed the learning problem factor (LP).

For selection purposes, three levels were distinguished for each (AP and LP) factor: level 1, with both scores on a factor higher than or equal to the mean score; level 2, with one score higher than or equal to the mean; and level 3, with both scores on a factor lower than the mean score.

One group, consisting of 22 children, was defined as having attentional problems (AP) with a level of 3 on the AP factor, and level 1 or 2 on the LP factor. Another group, consisting of 18 children, was selected as having learning problems (LP), with a level of 3 on the LP, and a level of 1 or 2 on the AP. Finally, 20 children served as the control group (NC), with a level of 1 or 2 on the AP and the LP, but without attaining a 2 on both factors.

In addition, a hyperactivity score was derived for each child from a separate restlessness scale of the Amsterdam Behavior Questionnaire (de Jong & Das-Smaal, 1991). In order to control for IQ differences, intelligence levels were determined by the Raven IQ test.

Half of the subjects took part in the current study (AP 9, LP 9 and NC 10), while the other subjects participated in another ERP study. Subjects wearing glasses kept them on during the experiment.

Apparatus

Electroencephalogram (EEG) and electrooculogram (EOG)

Standard tin Electro-cap electrodes were used for monopolar EEG derivations. The electrode positions were F3, Fz, F4, C3 ,Cz, C4, P3, Pz, P4, O1 and O2, according to the 10-20 system. Inactive references (A1-A2) were used as linked ear electrodes. Electrodes in plastic cups were used for the EOG. By means of adhesive rings the electrodes were placed at the outer canthus of each eye for the horizontal EOG. Infraorbital and supraorbital electrodes were placed in line with the pupil of the left eye for the vertical EOG. The ground electrode was placed at the forehead. Eci Electro-Gel paste was used. Resistance in the electrodes was never higher than 3 kohm. The signals were pre-amplified and filtered by a Nihon Kohden 14 channel polygraph. Low-pass frequency was 30 Hz for both the EEG and EOG. The time constant was 5 seconds for the EEG and 25 seconds for the EOG. Subsequently the signals were sent to the analogue inputs of an Olivetti M-280 computer for analogue-digital conversion (scientific solution A/D board). The sample rate was 100 Hz and started 250 msec before stimulus onset and lasted 1850 msec.

Stimuli

Figure stimuli as depicted in Figure 1 were presented in a series of 20 stimulus presentations to each child individually. Each stimulus presentation consisted of a display with 8 locations on a circle with a diameter of 14 cm. On each of the 8 positions one figure from a pool of 25 geometrical figures was plotted. The diameter of the figures was 5 cm. All figures on the 8 positions were different. However, one of the figures was identical to one of a set of two figures, which had been presented as a to-be-remembered set (memory set) before the start of the series. This figure was a member of the memory set. The subject had to search for this figure and to decide whether a member of the memory set was present. By pressing one of two RT-buttons (left or right) the subject indicated which figure he had seen. During the interstimulus interval (ISI), which lasted between 4.5 and 5.5 seconds, a fixation mark was present in the center of the screen. The location of the target within each series was either random or fixed.

Procedure

Subject lay on an examination table in an acoustically and electrically shielded room. The upper portion of the examination table

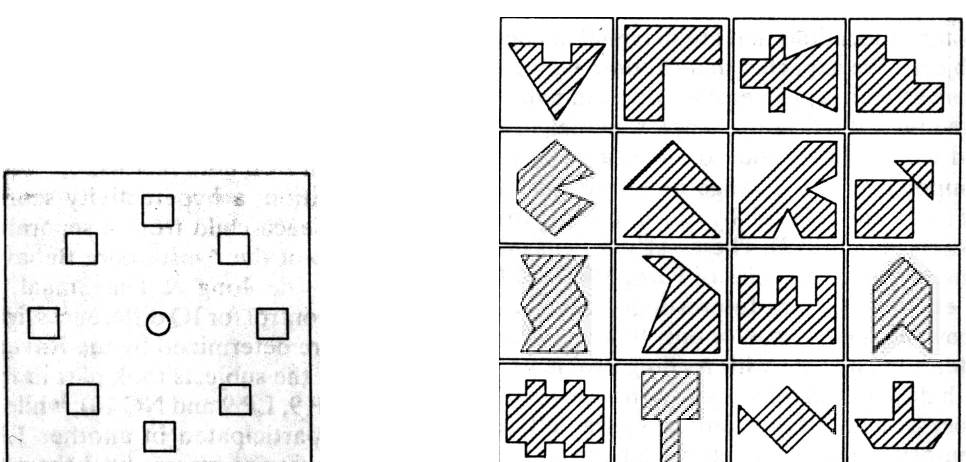

Figure 1 a) The stimulus display with 8 figure positions. On each position one out of a set of 16 figures is presented. One of the positions contains a target figure. b) The set of 16 figures. Two of these figures were randomly chosen for the memory set and served as targets. The other figures were used as distractors.

was adjustable, so that the subject's head could be positioned roughly parallel to a monitor (12 inch, amber) which was positioned above and in front of the subject's eyes at a distance of 60 cm. In this way the subject's head was fixed in the vertical direction. Clamps were used to fix the subject's head in the horizontal plane so that the center of the screen was in the center of the subject's visual field. The experiment started with a 5 minute adaptation period.

Series of 20 numbers were used for training purposes. These training series were repeated until the subjects reached a criterion score of 95% correct RTs. Subsequently the experimental series of 20 displays was presented. A memory set of two figures was presented first, and the subject was instructed to memorize these figures very well. He or she was told that one of these figures (a target) would be presented in each display of a series, and that the goal was to search for this target. If the left figure of the memory set was presented in the display, a left RT button had to be pushed. If the right figure of the memory set became visible as the target, a right button had to be pushed. To ensure that the figures were correctly memorized the memory set and instruction were presented a second time before the series of 20 displays. The location of the target and of the two targets themselves was randomized. A target never appeared more then twice in the same location on the display in successively presented trials. As soon as the subject made fewer than 5% incorrect RT-button pushes within the training series, the experiment was started. Before each series of 20 displays a new memory set was presented. The subject was not informed about the location of the targets in the displays or about the nature of the series, random or fixed. This had to be learned by the subject during the presentation of the series. This learning was assumed to occur somewhere between the first and last trials of the fixed series. Each subject received five series with a fixed target location and five series with a random target location successively (see Figure 2). Altogether, ten series were presented in random order, with the restriction that two identical fixed or random series never followed each other. Half of the subjects started with a fixed series, the other half with a random series.

Scoring

RTs

The subject was required to make a choice between the two members of the memory set by pressing a left or a right button at each trial, with both left and right button presses being pooled by the computer, but only correct responses which occurred within an interval of

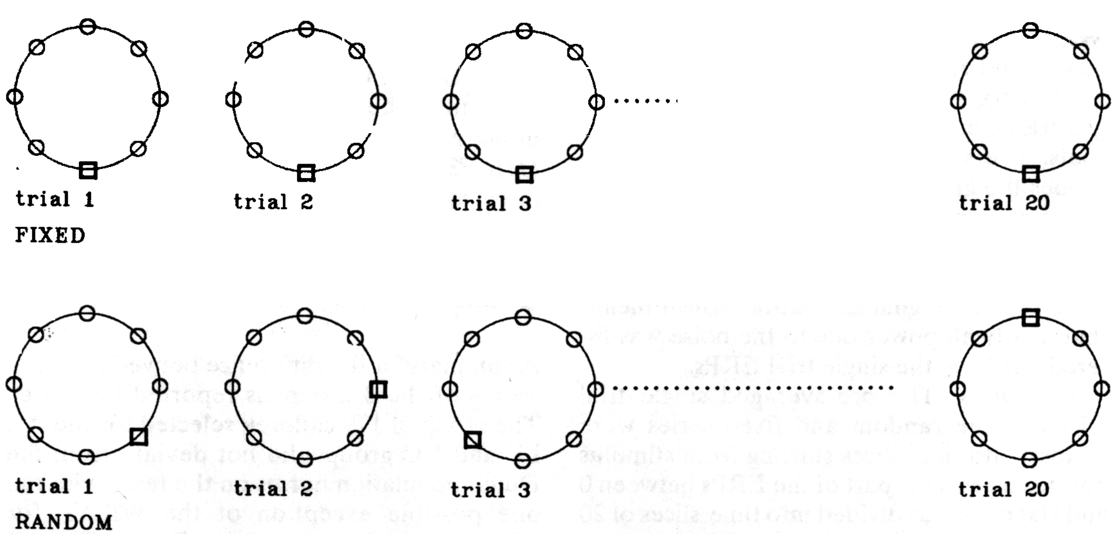

Figure 2 The presentation of the target stimuli in 8 position displays. The upper series is a series with a fixed target location and the lower series one with a random target location. The targets are represented by bold squares and the distractors by circles.

100 msec to 5000 msec after the stimulus onset were entered into the analysis. This relatively long time was necessary because in uncertain conditions eight positions of the display had to be scanned to detect which target was presented. These correct RTs were averaged over equal positions in the fixed or random series. Twenty fixed RTs and twenty random RTs were available for each subject.

ERPs

All EEGs were checked for clipping, whereby clipped EEGs were replaced by unbiased estimates. The EEGs were corrected for EOG-artifacts according to the method of Woestenburg et al. (1983a) and van Driel et al. (1989), by a regression analysis in the frequency domain. Vertical artifacts account for the largest part of the covariance, and thus this artifact was removed first. Finally, residual horizontal artifacts were subtracted from individual trials.

Traditional averaging within series was not possible because a change in cortical responses and in RTs was expected, especially in the fixed series, and just such a condition violates the averaging evoked potential model. Therefore, EEG segments belonging to correct RTs were pre-averaged for identical position in the fixed or random series. Twenty fixed and twenty random EEGs with an evoked response were obtained. Next, pre-averaged single trial ERPs were estimated with the Orthogonal Polynomial Trend Analysis (OPTA, Woestenburg et al., 1983b), a method which estimates linear, quadratic, cubic, etc., trends over successive trials. The sum of these trend functions describes the gradual changes from trial to trial, e.g., a response decrement during habituation within a few trials. Trend coefficients are tested for significance. Only significant coefficients were used for signal estimation, which means that nearly all power due to the noise was filtered out from the single trial ERPs.

Time-Slices: The pre-averaged single trial ERPs of the random and fixed series were divided into time slices starting from stimulus onset. The earliest part of the ERPs between 0 and 800 msec was divided into time-slices of 20 msec, a range in which P120 and N200 components are present. The complete ERP was divided into time-slices of 40 msec to cover the period of 0 to 1600 msec. Each time slice was the average of two and four samples, respectively.

Subsequently, all time-slices of difference waves (event contrasts) were tested for the presence of significant differences between conditions within groups, and all time slices of events were tested between groups (including difference wave contrasts). Corrections for the degrees of freedom were applied according to Yamane (1973, p. 669) if variances differed between groups.

Finally, a multivariate analysis of variance (BMDP) was performed in order to determine which time slice of 40 msec showed a difference between the fixed and random series, and which was the first trial of the series at which the difference reached significance. We used trials 1, 3, 5 and 7 because we expected the that the subjects would master the regularities in the fixed series within this time interval. Further increases or decreases of differences between conditions (difference waves) and groups were studied by comparing the mean of trials 5, 7 and 9 with the mean of trials 11, 13 and 15. For illustration, difference waves will be presented in which ERPs of the fixed series are subtracted from those of the random series. Within each figure, graphs are presented of critical and observed F-values. A difference is significant if observed F-values exceed a critical F-value ($p = 0.05$).

Components

Latencies of ERP components were determined on the basis of the time-slice analysis. We defined the compnents thus: P120: 100–150 msec; N200: between 180 and 220 msec.; an early P300: 280–340 msec; a late P300: 38–500 msec; and Slow Waves (SW): 800–1600 msec.

Results

A summary of the difference between the test scores of the 3 groups is reported here first. The group of 179 children selected for the AP, LP and NC groups did not deviate from the Dutch population norms on the tests, with the one possible exception of the WRAT, for which norms are not yet available. The AP group was significantly slower in performance on the Bourdon-Vos attention test (Vos, 1988) in comparison to the LP group ($t(36) = -4.69$, p = .000) and to the NC group (t(33) = 3.22, p = .003). The AP group also differed from the LP and NC group on the attention score of the Amsterdam Behavior Questionnaire for teachers (t(37) = 2.15, p = .039 and t(36) = 8.06, p = .000, respectively). However, a separate hyperactivity score on the ABQ did not differ significantly between groups. The LP group differed from the AP and NC group on the BRUS (t(37) = -4.91, p = .000 and t(37) = -3.44, p = .000, respectively).

The Bourdon-Vos attention scores of the AP group were 1 standard deviation (s.d.) slower than those of the LP and NC group. The ABQ attention scores of the APs were 1.33 s.d. above the Dutch population mean, those of the LPs were 0.73 s.d. and those of the NC were 0.28 s.d. below the population mean. LPs were 1.75 s.d. below the Dutch population on the BRUS. APs and NC were 0.9 s.d. above the population mean. The mathematical test of WRAT did not differentiate between the LP and AP group, with the LPs scoring slightly lower than APs, but a significant difference was found between the LP and NC group (t(37) = -6.16, p = .000), and a difference of 2.65 s. d. was observed here. Therefore, APs and LPs differed mainly on technical reading.

Mean Raven IQ scores were 35.18 for APs, 36.15 for LPs and 39.48 for NCs. Mean age was 11 yr 1 month for APs, 11 yr 2 months for LPs and 10 yr and 11 months for NCs. No significant differences between groups were found for IQ scores or age.

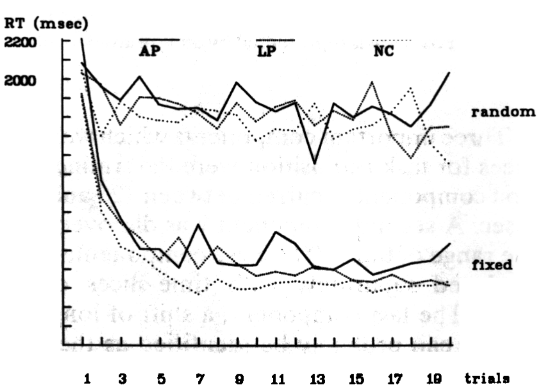

Figure 3 RTs to the figure displays of Figure 1 of the children with attentional problems (AP), the children with learning problems (LP) and control children (NC) for the random (upper traces) and fixed condition (lower traces). Each trace represents the responses on the 20 trials of a series.

In summary, the conclusion is that the groups differed on specific capacities only. APs differed on attention scores compared to LPs and NCs. LPs only differed on technical reading compared to APs and NCs. None of the groups differed in respect to hyperactivity.

RTs

Figure 3 presents the average trial to trial RT data for the AP, LP and NC groups of children for the fixed and random conditions. No decrease in RT over trials occurred to randomly presented targets. However, RTs to fixed targets decreased within a few trials to an asymptotic level. This decrease was significant starting from the third trial in all groups (F(1,8) = 17.6 for AP, 10.04 for LP, and 42.25 for NC, p < 0.05). No significant difference was found in task-acquisition between groups. However, RT responses to targets showed that the AP group had longer latencies in the fixed condition. The delay amounted to about 150 to 200 msec compared to the normal group (F(1,19) = 4.54,p < 0.05). During the first part of the fixed series, RTs of the LP group were slightly slower than those of the NC group. However, this difference was not significant.

Response errors are given in Figure 4. In general, more errors were made in the random condition than in the fixed condition (chi-square = 51.14, p < 0.001). The AP group made more errors in the fixed condition as compared to LP's and NC's (chi-square = 5.13, p < 0.05).

ERPs

Time-slices

Task-acquisition: Task acquisition was defined as an increasing difference over trials between the fixed and random conditions. The maxi-

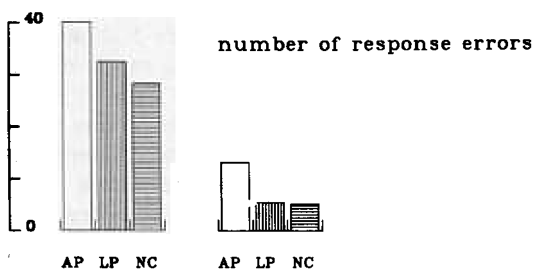

Figure 4 The number of response errors made inthe fixed (right bars) and in the random conditions (left bars) for the children with attentional problems (AP), the children with learning (LP), and the control children (NC).

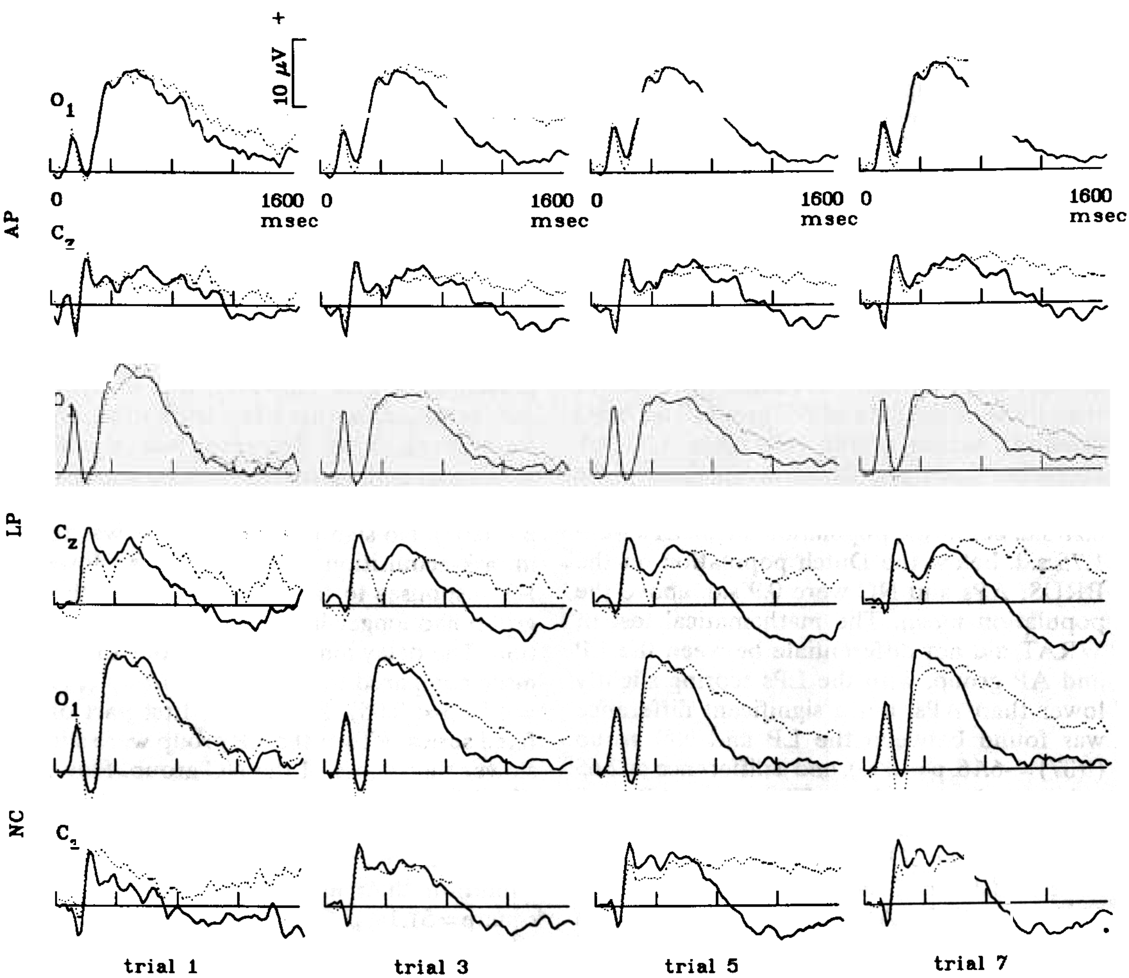

Figure 5 The superposition of random (dotted lines) and fixed (solid lines) C_z and O_1 ERPs in the children with attentional problems (AP), the children with learning problems (LP) and the control children (NC). An increase in difference develops over trials 1, 3, 5 and 7. In children with attentional problems an occipital distribution is evident and in children with learning problems a central distribution (1 cm is 1 µV). Positivity is represented by an upward deflection.

mum difference was reached within 5 to 7 trials and was predominantly present in the second part of the ERP, the SW. Figure 5 shows the occipital and central ERPs to random and fixed stimuli on trials 1, 3, 5 and 7 of the series of 20 trials. These electrode locations were chosen because topographical differences were most evident in these leads. The MANOVA over succeeding time-slices confirmed that several components were influenced by this experimental manipulation. The strength of the contrasts of time-slices between random and fixed stimuli is shown in Figure 6. A minor number of significant time-slices was discovered at trial 1.

Three important components which were indices for task acquisition were determined. A first component occurred between 120 and 200 msec. A second component was discovered in the range of the P300. These components were analyzed separately with time-slices of 20 msec. The last component, a shift of long duration, can probably be identified as the SW. This shift was significant in the NC group from 880 msec from stimulus onset, and in the AP and LP group from 1040 msec (in parietal leads). During acquisition of the task (trials 3, 5, 7) the AP group had a posterior distribution, while the LP and NC group had a more central distribution of the SW. The posterior SW was

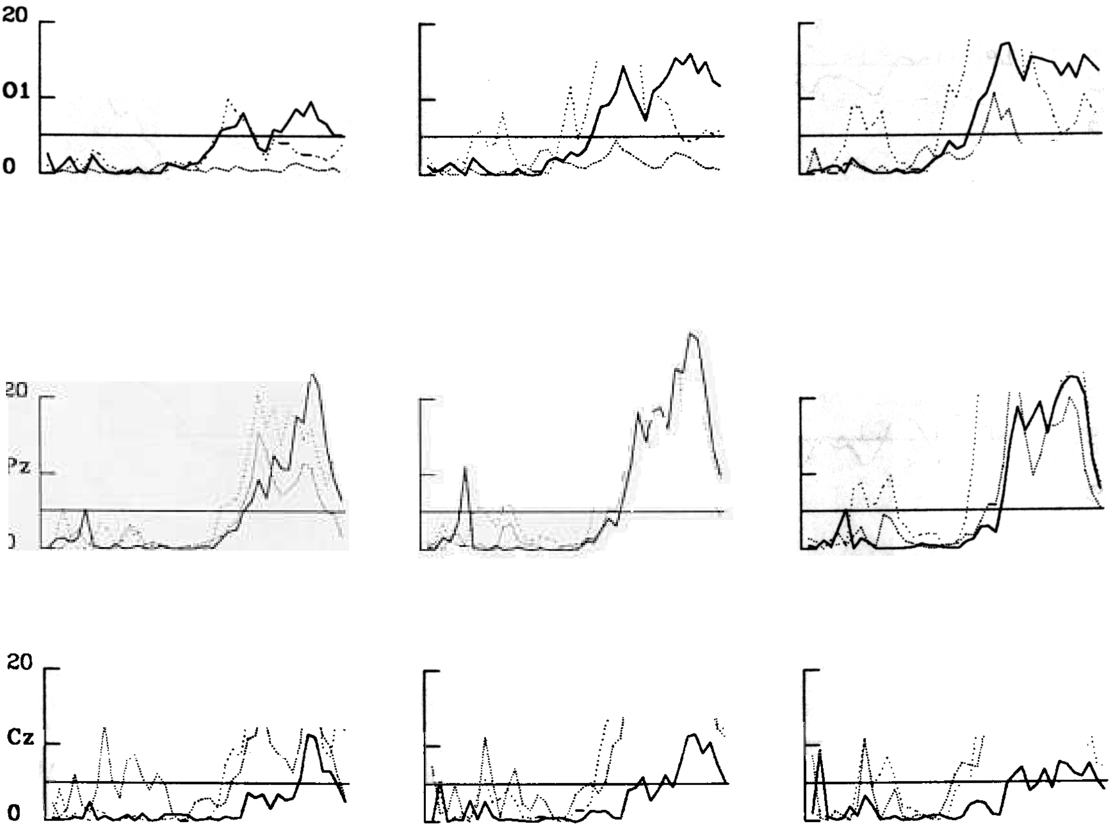

Figure 6 The F-values of the Multivariate test of the difference between the random and fixed conditions of figure stimuli for sequential time slices between 0 and 1600 msec after stimulus onset. The upper traces contain the values of O_1 for trial 3, 5 and 7, followed by P_z and C_z. Values above the horizontal lines are significant at a 5% level or less. The size of the F-values is given on the y-axis. Children with attentional problems (——), children with learning problems (.........), control children (.......).

delayed with 160 msec in both LP and AP group during acquisition (see Figures 5 and 6).

Effects of spatial location on ERP-components

P120–N200: The figure stimuli evoked the strongest P120-N200 complex at the O1 and O2 electrode positions. It was reversed in polarity at the frontal leads. The evoked amplitudes of the posterior P120 and N200 for both the fixed and random displays were smaller in the AP group than in the NC and LP groups (see Figure 8). The control subjects (NC) had P120 and N200 components which significantly changed in amplitude over trials in response to fixed spatial locations of the target. Both the P120 and the N200 became more positive. During the first trials there were no differences between ERPs evoked by fixed or by randomly presented stimuli. However, this difference became visible and increased over the next trials. Figures 7 a and b show these difference waves for a second block of trials (mean of trials 5, 7 and 9) and a third block of trials (11, 13 and 15). An occipital, parietal and central difference wave during the second block developed at 200 msec (N200) for the NC group (see the first column of Figure 7a and b), while only an occipital difference was present for the AP group ($F(1,8) = 6.97$, $p = 0.0297$ at O1). The LP group did not show a significant difference be-

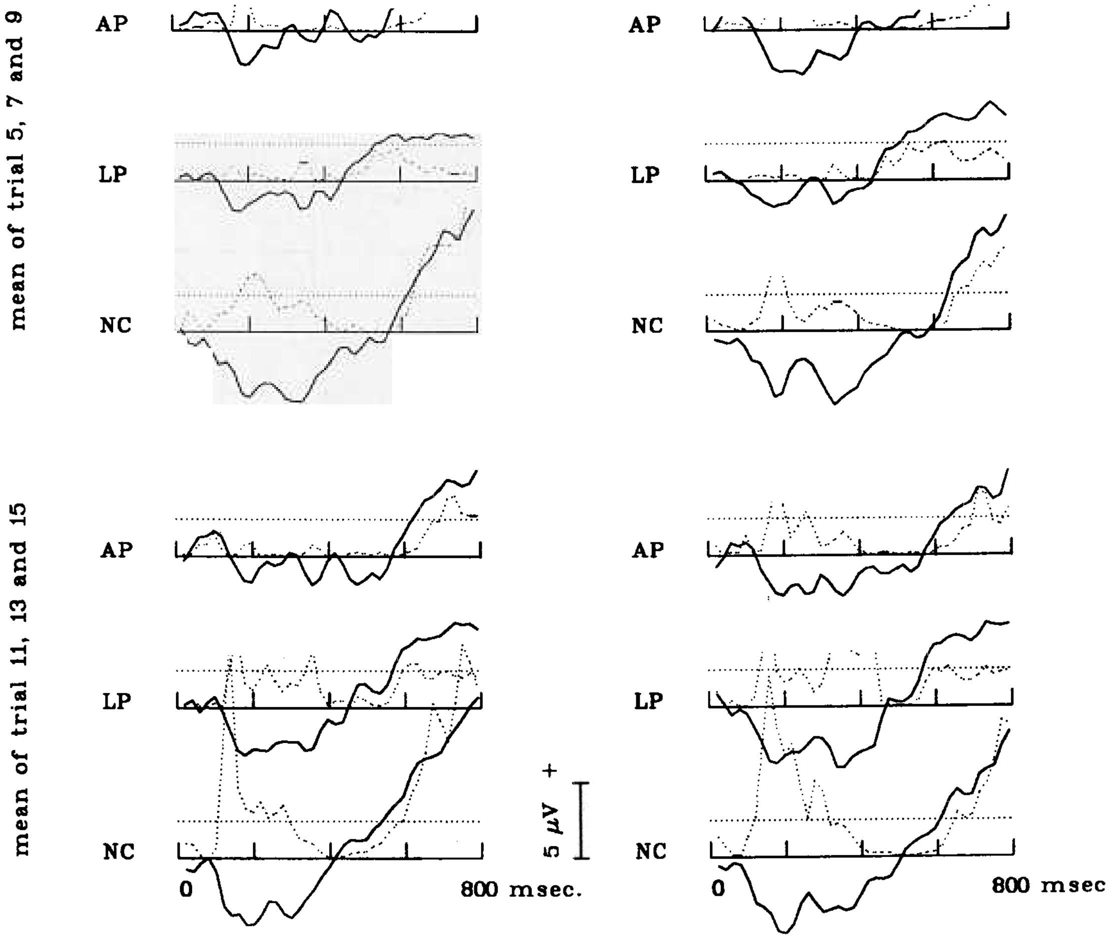

Figure 7 a) The increase of the early event difference of the occipital ERPs. An early event difference between random and fixed ERPs, initially not present at trial 1 develops over trials. It is largest in the NC group and strongest at the P120 component. The solid curve is the difference ERP between random and fixed ERPs, the dotted line is the associated F-value (dfs 1,8 for children with attention problems and children with learning problems, 1,9 for control children; p = .05 two-tailed). The difference between events is significant above the dotted horizontal line (F-value 10 = 1 cm).

tween conditions at the P120-N200 range during the second block. However, they did so during the third block (see the second column of Figure 7a and b, e.g., $F(1,8) = 9{,}57$, $p = 0.0148$ at O1 on 180 msec). The earliest and strongest evidence for an event contrast developed in the third block for the control subjects, peaking at 140 msec ($F(1,9) = 29.20$, $p = 0.0004$ at O1 and $F(1,9) = 23.93$, $p = 0.0009$ at O2). The P120 to fixed stimuli was smaller in the APs compared to NCs ($F(1,17) = 6.80$, $p = 0.0177$ at O1; $F(1,17) = 12.69$, $p = 0.0033$ at O2). Event contrasts in APs were smaller than those in LPs ($F(1,16) = 8.11$, $p = 0.011$ at O1).

At the parietal and central leads, the earliest contrast between fixed and random targets in control subjects was discovered at 220 msec (N200) after stimulus onset in the second and third block. Its strength increased in the third block (see Figure 7b.; $F(1,9) = 30.22$; $p = 0.0004$ at P4; $F(1,9) = 38{,}72$; $p = 0.0002$ at C4). Parietal N200 contrasts were not present in the LP and AP group. Both the second and third block for the LP group had a Cz contrast in the range of 220 msec. The AP group differed only during the second block at Cz (see Figure 7b). These N200 effects are separated from the later P300 contrasts, as can be seen from Figure 7b.

Early frontal (Fz) contrasts were visible only in the NC group at 100–160 msec. ($F(1,9) = 17.82$; $p = 0.0022$) and at 240 msec in the LP group. The frontal contrasts of the AP and LP

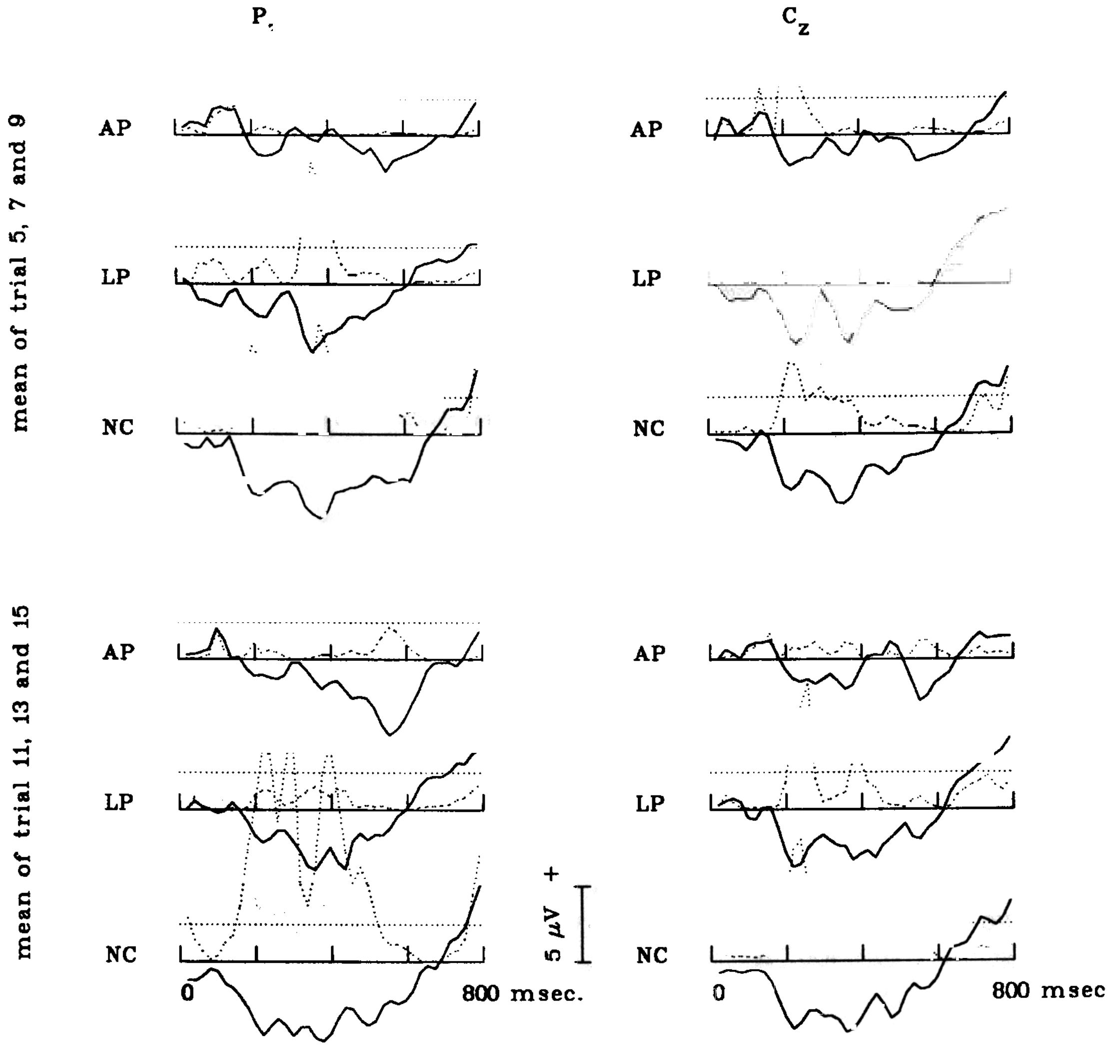

Figure 7 b) The increase of the early event difference of the parietal and central ERPs. An early event difference between random and fixed ERPs, initially not present at trial 1 develops over trials. It is largest in the NC group and strongest at the P120 component. The solid curve is the difference ERP between random and fixed ERPs, the dotted line is the associated F-value (dfs 1,8 for children with attention problems and children with learning problems, 1,9 for control children; p = .05 two-tailed). The difference between events is significant above the dotted horizontal line (F-value 10 = 1 cm).

group differed significantly from each other at 200 msec ($F(1,18) = 10.32$; $p = 0.0064$).

P300: When location was predictable, parietal and central P300s of the AP group were delayed with about 200 msec compared to the NC group, but no amplitude difference was discovered between P300s of APs and NCs. The difference in latency between the NC and AP group was larger at trials 5, 7 and 9 (see Figure 8), but it was already present at the first trial. The P300 to fixed targets decreased over trials in the LP group. At the 5th, 7th and 9th trials, the amplitude of the P300 of the LP group was significantly smaller as compared to the NC group ($F(1,17) = 4.98$; $p = 0.0405$ Pz 360 msec).

Within groups it was found that the P300 to fixed targets in the NC group became significantly larger in amplitude over trials compared to P300 on random targets ($F(1,9) = 14.60$; $p = 0.0041$ at 380 msec, and $F(1,19) = 28.46$; $p = 0.0014$ at 400 msec). These contrasts were at a maximum on the parietal leads. A similar contrast (fixed versus random) was present in the LP group. However, it occurred here at Pz only during the second block and on Cz during the

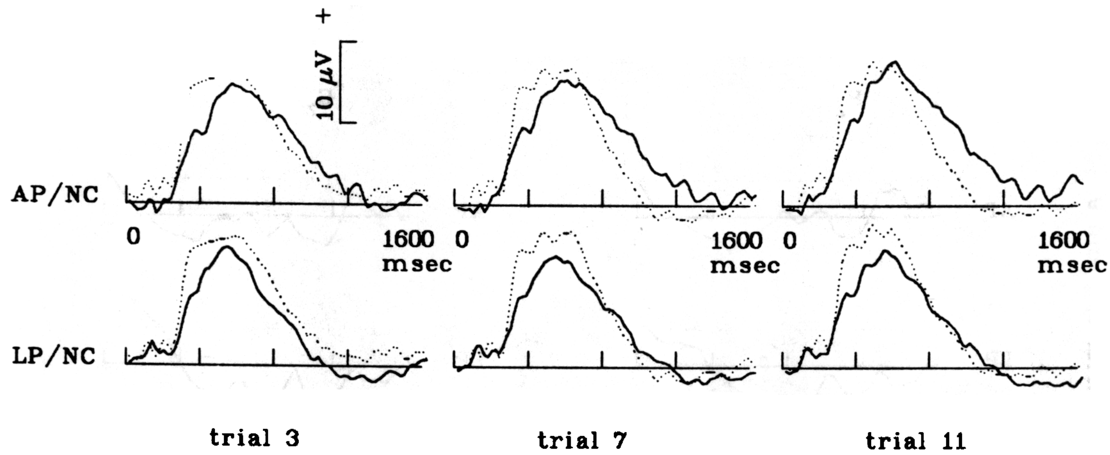

Figure 8 The amplitude and latency difference of the parietal P300 of the fixed condition between groups. The dotted lines are ERPs of the control group, the upper solid lines those of the children with attentional problems and the lower solid lines are the ERPs of the children with learning problems.

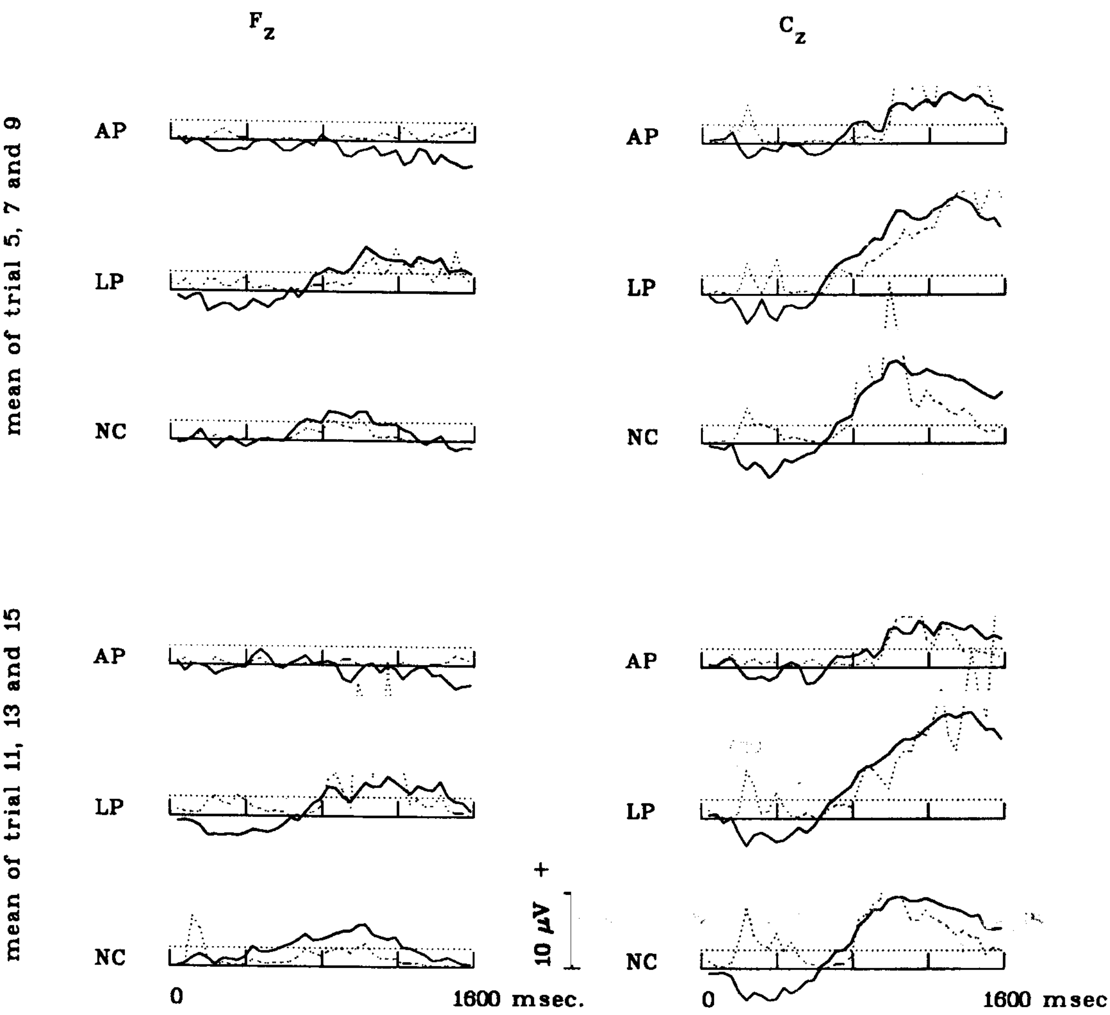

Figure 9 a) The SW event difference of the frontal and central ERPs. A SW event difference between random and fixed ERPs, initially not present at trial 1, develops over trials. The solid curve is the difference ERP between random and fixed ERPs, the dotted line is the associated F-value (dfs 1,8 for children with attention problems and children with learning problems, 1,9 for control children; p = .05 two-tailed). The difference between events is significant above the dotted horizontal line (F-value 20 = 1 cm).

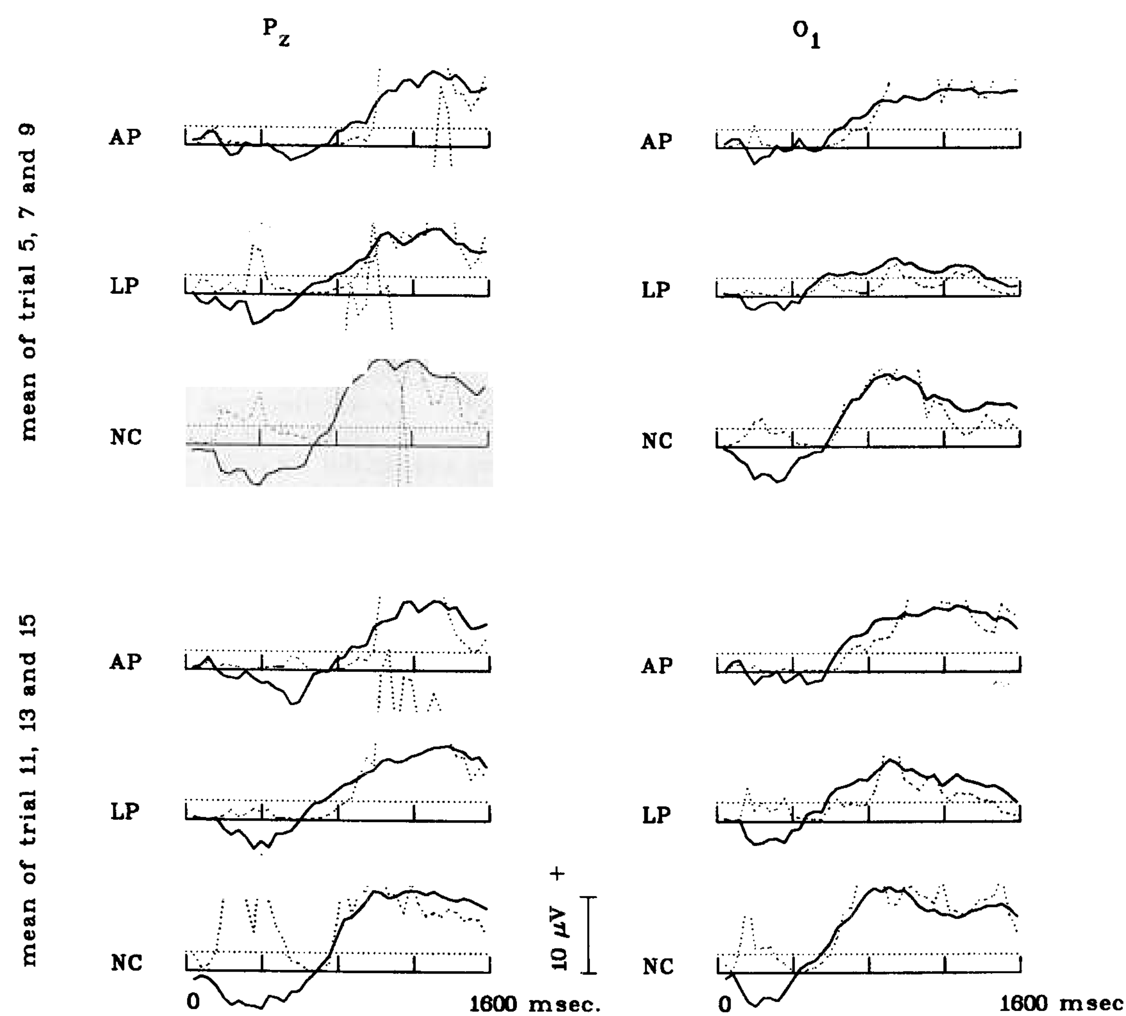

Figure 9 b) The SW event difference of the parietal and occipital leads. A SW event difference between random and fixed ERPs, initially not present at trial 1, develops over trials, but no further increases occur over blocks. The solid curve is the difference ERP between random and fixed ERPs, the dotted line is the associated F-value (dfs 1,8 for children with attention problems and children with learning problems, 1,9 for control children; p = .05 two-tailed). The difference between events is significant above the dotted horizontal line (F-value 20 = 1 cm).

second and third block ($F(1,8) = 16.26$; $p = 0.0058$ at 360 msec; $F(1,8) = 10.64$, $p = 0.0115$ at 380 msec; $F(1,8) = 6.47$; $p = 0.0345$ at 400 msec, respectively). The P300 event contrast differed significantly between the AP and NC group at Pz ($F(1,17) = 7.73$, $p = 0.0122$). There were no P300 contrasts (see Figure 7) for the AP group. No clear P300s were evoked at the frontal leads, except at F4 for the LP subjects. An effect in the range in which the P300 usually manifests itself, developed during the third block ($F(1,9) = 16.632$; $p = 0.0036$ at 360 msec). The latency and the strength of the contrasts at Pz and O1 are graphically presented in Figure 7a and b. The P300 effects behave differently from earlier contrasts in strength and topography.

SW: The P300 was followed by a SW of long duration which was positive in the random condition, but became negative after a few trials in the fixed condition. A topographical difference of the contrast development was seen between the groups, with the AP group having an occipital distribution and the LP group a central distribution (see Figure 5 and 6). The central distribution of the latter group extended to the frontal locations.

Frontal, central, parietal and occipital SW contrasts did not further increase over the second or third block (see Figure 9a and 9b). In general, frontal contrasts were small and only significantly present in the LP and NC group. At Cz, SW difference waves were significant for all groups. However, the onset of the SW contrast was 200 msec later in the AP group than in the NC and LP group (see Figure 9a and 9b). Occipital contrasts were smaller in the LP group, and normal control subjects responded with shorter latencies in the SW at Pz (800 msec). The separation of conditions in the AP group occurred here at 980 msec. The parietal delay in SW for the LP group was about 100 msec.

The frontal and central SW contrasts differed significantly between the LP and AP group ($F(1,16) = 10.06$; $p = 0.0053$ at Fz on 1200 msec, and $F(1,16) = 6.88$; $p = 0.017$ at Cz on 960 msec) and between the LP and NC group ($F(1,16) = 5.52$; $p = 0.029$ at Cz on 1500 msec). The SW contrasts in the NC were between those of the AP and LP group. At the end of the occipital SW a significant difference in contrasts also developed between the LP and AP group ($F(1,16) = 7.76$; $p = 0.0124$ at O1 by 1400 msec).

The SW contrasts were first present at the occipital leads (at about 600 msec). No onset differences became visible in the groups on the other leads, except at the parietal leads presented above, and at frontal leads where contrasts became small. The SWs during the random condition did not differ between AP and LPs. However, those of the fixed condition did. APs had smaller, less negative, SWs at the central and parietal leads ($F(1,16) = 14.78$, $p = 0.0027$ at Cz; $F = 10.46$, $p = 0.0057$ at Pz). These differences were somewhat enhanced at the right hemisphere.

Discussion

This study dealt with children taken from a normal school population, but with attentional (AP) and learning problems (LP). They were compared to each other, and to a control group (NC) on behavioral (RT) and ERP measures. The groups differed from each other on several tests, but the sample from which the 3 groups were drawn did not deviate from the Dutch population of elementary school children. AP subjects scored more poorly on an attention test and were rated worse on classroom attention by their teachers, while LP pupils scored poorer on a technical reading test compared to both other groups. Performance of LP and AP on arithmetic was the same, but worse than with the NC group. Interestingly, Raven IQ scores and age did not differ between groups. The groups also did not differ from each other with respect to the teacher ratings of hyperactivity. The results of this study show that APs had slower RTs and that their early ERP components (P120 and N200) were smaller compared to LPs and NCs. In addition, the latencies of the P300 and SW were delayed. LPs evoked smaller P300 and delayed SWs during the acquisition period of the task. The latencies of both RTs and the number of errors were the same as for NCs.

We want to stress here that the study was explicitly not aimed at examining clinical groups. Thus. the groups selected in this study cannot be characterized as ADD or dyslectics. In line with test habits in school counseling centers, the Bourdon-Vos attention test was used as a selection instrument for the AP-group, and teacher ratings were added. In the Bourdon-Vos test, perceptual speed is an important factor (de Jong, 1991). Compared to ADD and RD, the attention and learning problems of the AP and LP children were probably less serious and possibly of another nature. For instance, although attentional deficit is one of the main characteristics of ADD, this syndrome also encompasses other symptoms, like impulsiveness and hyperactivity. The latter aspect did not differ between groups in the present study. By using perceptual speed as a selection criterion for APs here, decreased attention was linked to earlier information processes rather than to output systems, which seem important in ADDH according to the van de Meere studies (1987, 1988a,b). However, despite these differences, the present results nevertheless might show some relations to findings of ERP studies on clinical groups, especially those studies using non-linguistic visuo-spatial stimuli, as outlined in the introduction.

The aim of the present study was to follow the dynamics of learning to attend to certain regularities in a visual search task. These regularities were in fact realized by the children in a few trials. RTs became faster within a few trials. However, APs were 150 to 200 msec slower in response to regular displays, while LPs performed as fast as normal subjects.

A trial to trial evaluation is possible for ERPs. Single trial ERPs were estimated with the OPTA (Woestenburg, et al., 1983b), which is a specific method for analyzing trends over trials. Adaptation of subjects due to learning cannot be studied with traditional averaging. A fairly difficult visual search task was employed. The influence of spatial attention was increased by using a relatively large display size of 8 complex pictures. A target was presented in two different series, using either a random or a fixed target position. The importance of using larger display sizes was recently demonstrated by Theeuwes (1990). He studied the various influences of attention on scanning displays of different sizes, concluding that display sizes of 4, which are not uncommon in visual search experiments, are less sensitive for measuring automation due to prior knowledge of target location. It was also shown that if the target was always placed in a unique figure so that the figure was a reliable cue for the target search (control trials), scanning was nearly independent of display size. If not, however, scanning time increased linearly with the display size. These scanning time increments, indexed by the RT, were comparable to the differences of RTs found in our fixed and random conditions. The three groups of the present study succeeded in task completion within 5 to 7 trials. Both RT and late ERP measurements showed the same speed of task acquisition, but these indices were slightly delayed in AP compared to NC, especially in the fixed condition. Trial to trial changes of early ERP measurements differed between groups. Several ERP components were identified, some of which differentiated between the AP, LP and NC children. Group differences were evident for the difference between both kinds of visual search series on the P120, N200, P300, SW, and on the RT.

A discussion of general issues and task effects will now be presented, then the focus will be on specific group differences.

Early components evoked by selection of simple stimulus attributes such as target location in selective attention paradigms (Hansen & Hillyard, 1984, Näätänen, 1982), are usually thought to reflect attentional level. The results of the present study support this assumption. As in the studies by Okita et al. (1985) and Wijers et al. (1989), visuo-spatial attention was indexed by an early component, a P120-N200 complex that consisted of two separate components. As to differences between the fixed and random conditions, an early occipital negativity superimposed on the P120 was found for the NC group. Evidence for a second difference between tasks was present on an occipital-parietal-central N200 for NC, and on a more central N200 for LP. Small early frontal differences were also present for NC and LP. As expected, all effects developed over a certain number of trials. The different attentional requirements to complete both kind of tasks were clearly observable in the P120-N200 complex over trials. No evidence for differences in attentional demands were found during the first trials of series. High attentional demands were required here on both tasks. However, during the fixed series, when the subjects' uncertainty about the target location was reduced, and the distracters in the display could be neglected more easily, the attentional demands diminished. In line with this, the early ERP amplitudes in the range of 200 msec became less negative. The decrease in the amount of attentional demands over trials as indexed by the P120 and N200 amplitudes was slower than in the task acquisition as indexed by the decrease in RTs over trials. The negativity decreased further after task acquisition was completed.

P300 is generally thought to reflect allocation of attentional capacity to information that requires some further processing (e.g., Donchin et al., 1986; Klorman, 1991). According to Looren de Jong et al. (1989) the concept of resource allocation between concurrent tasks (Norman & Bobrow,1976) can be extended to the allocation of attention in visual space. Hoffman, Houck, McMillan, Simons and Oatman (1985) and Looren de Jong et al. (1989) considered P300 amplitude as a measure of perceptual attention that is allocated to a target in visual space. The more perceptual attention is allocated, the larger the P300 amplitude. Looren de Jong et al. found diffuse P300s over a wide timespan in unpredictable conditions. In agreement with this a smaller, long-lasting positivity in the random series, the unpredictable condition, was present in this study, and the P300s were larger for the predictable targets in the fixed series. The diffuse long lasting positivity in the random condition is not due to an artifact of multiple P300s (Johnson & Donchin, 1985), because these are removed by the OPTA, a technique that selectively filters errors from the ERP (Woestenburg et al., 1983b). This long lasting positivity is associated with more complex processing, (Friedman, Vaughan & Erlenmeyer-Kimling, 1981), in our case a serial search for a target. It is also in accordance with the increase of RTs. As for the latency of the P300, Klorman (1991) mentioned a number of studies that show a relationship between P300 delay and cognitive and perceptual load. The P300 latency slows down as the mental load increases in a memory search task. This suggests that this latency marks the end of stimulus evaluation processes preceding response selection. In the present study, a marked delay was found in AP children. This will be discussed below.

Ruchkin and Sutton (1983), Rössler, Clausen and Sojka (1986) and Looren-de Jong (1989) argued that the SW is associated with continued processing or memory updating following initial stimulus evaluation, reflected by the P300. Others (Karis, Fabiani & Donchin, 1984) also suggested a relationship to the depth of processing in working memory. Topographical aspects seem to be relevant. According to Loveless, Simpson and Näätänen (1987) frontal and parietal SWs dissociate from each other. Frontal SWs are more sensitive to the level of stimulus complexity than parietal SW's (Näätänen, Simpson & Loveless, 1982). Regarding the SW latency, Picton et al. (1986) argued that this aspect is related to the speed of information processing, and even more to the time taken for sensory analysis than for final response selection. The development of SW differences from trial to trial is quite clear in the present study. Topographical differences between groups are also apparent here.

The present study was aimed at discerning distinctive patterns of ERP components in children with attentional problems and those with learning problems. The results on the AP group showed the following: For the APs, a P120 and N200 difference between conditions was almost absent. Moreover, amplitudes of P120 and N200 in the fixed condition were also smaller for AP than for LPs and NCs. This suggests a diminished selective attention to the target location in the present visuo-spatial search task in APs.

In contrast to other groups, the APs showed no P300 amplitude difference between tasks. The P300 latency of the AP compared to the NC group was delayed by 150–200 msec. The delay increased over trials. Manifestations of task differences on the occipital, parietal and central SWs and the RTs were delayed by an equal amount of time. This indicates that stimulus evaluation processes take more time in APs (e.g., Magliero, Bashore, Coles & Donchin, 1984). As in the Holcomb et al. (1985) study, the results on P300 may be taken as an indication of a breakdown in the efficiency of attention allocation over time. The fact that APs also made more errors, supports an explanation in terms of lack of attentional efficiency. In fact, this lack can perhaps be further specified in the present study. The fact that the P300 of AP children was especially delayed to fixed figure stimuli could mean that the AP group had greater difficulty in building up an expectation in the fixed series as to where the target would be presented. Accordingly, it was harder for them to direct their visual attention to the target location. This explanation supports the findings of an absence of a P300 difference between the two series, while such a difference was reflected in larger P300 amplitudes for fixed compared to random series for LP children and for NCs.

As for the SW, a remarkable distribution difference was visible between AP and LP children. APs responded with larger occipital SWs and SW differences, whereas LPs had stronger fronto-central SWs and SW differences, which were maximal in the central region. The smaller amplitudes of ERP at the fronto-central cortex of APs were also evident in ADDH children. Satterfield et al. (1988) found small processing negativity in ADDH at frontal locations, and Lou, Henriksen and Bruhn (1984) found abnormally low regional cerebral bloodflow in the frontal lobes in ADDH children. More generally, attentional deficits are thought to be associated with frontal lobe dysfunction (e.g., Stuss & Benson, 1986). The present results show that even in a non-clinical group of subjects with attentional problems at school, frontal functioning is diminished.

Contrary to most RD studies, complex non-linguistic, visuo-spatial stimuli were used in the current study. This stimulus material was not specifically chosen for the LP group which was especially selected for purposes of diagnostic specificity, that is, to differentiate attention deficits from reading/learning deficits in elementary school children. Reading impairment can range from mild to severe. Although our subjects performed poorer than normal pupils on technical reading, their deficits were not as serious as in clinical RD groups. The present LP group nevertheless showed smaller parietal P300 to fixed targets compared to normals, and their adaptation to task differences was relatively slow, as indicated by the development of difference waves in the P120/N200 complex. In addition, a delay in the parietal difference SW for LPs was visible during the first trials, but not during the subsequent part of the series. These results seem to suggest that LPs have more problems in task acquisition, initially taking more time for sensory analysis (Picton et al., 1986). However, fronto-central difference SWs were large and not delayed (see Figure 4), and RTs were not delayed either. This difference SW might resemble a later frontal stage of selection negativity (Nd) usually found in selective attention. This second component of the Nd is larger and develops later at longer interstimulus intervals. According to Hansen and Hillyard (1984), this component might reflect prolonged rehearsal of stimulus selection-specific cues. Together with the task acquisition problems it therefore seems plausible that LPs do become involved in continued stimulus evaluation, but do it more slowly and less efficiently. In line with this suggestion about poor task acquisition, Swanson (1987) concluded that disabled readers form memory traces which are inferior to those of skilled readers. He suggested that learning disabilities can be characterized by a storage deficit.

In summary, the current study suggests that a number of brain deficits that are found in ADD and RD children are already present in a mild way in elementary school children who have attentional and learning problems. Importantly, these children did *not* belong to a clinical population and there were no differences in hyperactivity between APs, LPs and NCs. As complex spatial patterns were used as stimuli, where location was an important attribute, we assume that one of the first stages of visual information processing, the tecto-pulvinar pathway, was involved.

These results certainly support the conclusion that AP children have early deficits, smaller P120 and N200 components, and a delay in the ability to interrupt the stimulus evaluation process indexed by a delay in the latency of the P300. This indicates a lack of early attentional efficiency in visuo-spatial attention, probably related to a less efficient tecto-pulvinar pathway. All further processes are delayed by a similar amount of time, including those related to the RTs. LP children performed the RTs in a way comparable to control children, but their smaller parietal P300 amplitudes and their delayed parietal SW during the acquisition period of the task could have been the result of a limitation in memory functioning.

Another conclusion is that AP and LP children can be differentiated from each other by their unique topographical distribution of ERPs and the differences in the ERP components according to different stimulus conditions. APs had enhanced occipital ERPs and LPs had enlarged fronto-central ERPs. The task evoked an occipital distribution in AP, and a more centro-frontal distribution of ERPs in LP children, indicating less appropriate frontal functioning in AP children, and a prolonged process of memory updating in the LP group.

Contrary to Van der Meere and Sergeant's findings there was no evidence of delayed post P300 processes such as motor decision in the AP group. The latency of the P300 and onset of the SW were both delayed with 150 to 200 msec for APs in comparison to LPs and NCs. These differences would not have been found if cortical responses had had more variance. In that case any ERP amplitudes estimated would have been strongly reduced. In addition, a prolonged positivity was found in the random condition and at the first trials of the fixed condition that however decreased within a few trials. These clear trial to trial effects could only have been found with the OPTA.

Address for correspondence

Dr. J.C.Woestenburg
Department of Psychonomy
Psychophysiological Division
Free University Amsterdam
de Boelenlaan 1115
NL-1081 HV Amsterdam
The Netherlands

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Address for correspondence

Dr. J.C.Woestenburg
Department of Psychonomy
Psychophysiological Division
Free University Amsterdam
de Boelenlaan 1115
NL-1081 HV Amsterdam
The Netherlands

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