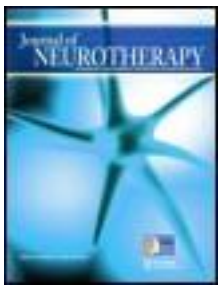

Journal of Neurotherapy: Investigations in Neuromodulation, Neurofeedback and Applied Neuroscience

Event Related Potentials of Subgroups of Children with Attention Deficit Hyperactivity Disorder and the Implications for EEG Biofeedback

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Published online: 18 Oct 2008.

To cite this article: Michael Linden PhD , Richard Gevitz PhD , Robert Isenhart BA & Todd Fisher BA (1996) Event Related Potentials of Subgroups of Children with Attention Deficit Hyperactivity Disorder and the Implications for EEG Biofeedback, Journal of Neurotherapy: Investigations in Neuromodulation, Neurofeedback and Applied Neuroscience, 1:4, 1-11

To link to this article: http://dx.doi.org/10.1300/J184v01n04_01

Event Related Potentials of Subgroups of Children with Attention Deficit Hyperactivity Disorder and the Implications for EEG Biofeedback

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This study examines differences in Event Related Potentials (ERPs) and Reaction Times (RTs) among two subgroups of Attention Deficit Disorder children: Attention Deficit-Hyperactivity Disorder (ADHD, children with attentional and hyperactive behavior problems), and Mixed (ADHD and ODD, children with attentional and aggressive behavior problems). The control group consisted of children with no history or behavioral symptoms of any of the above disorders. The two goals of this investigation were: 1) to assess the electrophysiological differences between ADHD, Mixed (which is the most commonly seen diagnosis for children in the United States), and normal control group children to clarify the physiological theories of this commonly seen disorder; and 2) to assess developmental age impact on the ADD subgroups' ERP differences.

Introduction

The diagnostic categories pertaining to disruptive behaviors of childhood have undergone a substantial revision in the last fifteen years. In the era of DSM-II (APA, 1968) and DSM-III (APA, 1980), hyperactivity or Attention Deficit Disorder (ADD) were widely discussed and treated. ADD continues to be the most frequently diagnosed and treated childhood disorder in our country; estimates of its frequency range between 3-15%. Although a general theoretical understanding of the disorder is lacking, formulations ranging from a biological to a more functional basis have been proposed.

In DSM-III-R (1987) and DSM-IV (1994), three Disruptive Behavior Disorders are specified: 1) Attention-Deficit Hyperactivity Disorder (ADHD), 2) Conduct Disorder (CD), and 3) Oppositional Defiant Disorder (ODD). Multiple diagnoses are allowed, and the most prevalent subgroup in clinical populations is a mixed form of these disruptive behaviors in which dual diagnoses of ADHD and ODD or CD are made. The overlap of symptoms of hyperactivity and inattentiveness with symptoms of aggression and conduct disorder presents a major diagnostic problem which has received considerable attention (Hindshaw, 1987; Milich, Loney, & Landau, 1982). The lack of a general theory and an adequate diagnostic classification system still persists for disorders of attention and hyperactivity.

The DSM-III-R categorical diagnoses of ADHD and ODD may be related to extreme placement on dimensions of behavior. Milich et al. (1982) depended on construct validity to develop the IOWA Conners Rating scales to assess the dimensions of Inattention/Overactivity and Aggression/Defiance. Swanson and Taylor (in press) have related this dimensional evaluation to the categorical diagnosis of ADHD and ODD/CD in the ICD 9 and DSM systems. Swanson and Taylor conducted research in the USA and UK using pure and mixed subgroups based on the use of categorical (DSM-III-R) and dimensional (IOWA Conners) criteria. The dimensional approach yielded invariant results across the two countries, so it was recommended over current categorical systems for defining subgroups.

In addition to behavioral dimensions of disruptive behavior disorders, developmental effects of age have been suggested in the

literature. Age adjustments may be particularly important in the evaluation of ADHD. Buchsbaum and Wender (1973), found a significant difference in Event Related Potentials (ERPs) between younger (6-9 years) and older (10-12) hyperactive children. Satterfield and Braley (1977), using similar age divisions, also found a difference between younger and older ADD children. Both of these early studies suggested that younger (under 9 years old) ADHD children may have larger than normal amplitudes for early components (N1 and P2) of the ERP (Buschbaum & Wender, 1973; Satterfield & Braley, 1977). It may be essential to consider both early components (P1, N1, and P2) and late components (N2 and P3) of the ERP separately because they have been reported to represent different physiological processes (Swanson, Sandman, Deutsch, & Baren, 1983).

More specifically, electrophysiological studies have assessed ADD with numerous theories explaining the children's behavior and the "paradoxical" effect of stimulant medication. The most common theories are of an abnormal underlying arousal level or a maturational lag in ADD children. The ERP components may be related to the type of processes proposed by Tucker and Williamson (1984) which separate general arousal (related to sensory orienting to novelty) and motor activation (related to action plans). These attentional processes are related to underlying neurotransmitter abnormalities (i.e. dopamine).

This study examined differences in Event Related Potentials (ERPs) and Reaction Times (RTs) among two subgroups of Attention Deficit Disorder children: Attention Deficit-Hyperactivity Disorder subgroup (ADHD, children with attentional and hyperactive behavior problems), and Mixed subgroup (ADHD and ODD, children with attentional and aggressive behavior problems). The control group consisted of children with no history or behavioral symptoms of any of the above disorders. The two goals of this investigation were: 1) to assess the electrophysiological differences between ADHD, Mixed (which are the most commonly seen children in clinics in the United States), and normal control group children to clarify the physiological theories of ADHD, and 2) to assess developmental age impact on the ADD subgroups' ERP differences.

Subjects

The subjects for this study were fifty-nine 5- to 12-year old boys and girls. Forty-five experimental subjects were recruited from referrals to the University of California Irvine Child Development Center based on Structured Parental and Child Interviews, and Teacher and Parent Iowa Conners Rating Scales. This diagnostic process yielded two subgroups: 1) children with ADD and hyperactive behavior (ADHD), and 2) children with ADD and both hyperactive and aggressive behavior (Mixed). Fourteen normal children (no scores above the ADHD cutoff on the Interviews and Rating Scales) from the local area served as the control group.

All children participated voluntarily after parental written consent was obtained. A nominal incentive, a small toy, was given to each subject at the completion of the ERP recording. All children who were previously taking any prescription medication were asked to remain off the medication, (i.e. Ritalin), for a minimum of 24 hours prior to recording their EEG.

Apparatus and Measures

Parent and Child Structured Interview forms, and Teacher and Parent IOWA Conners Rating Scales were used to diagnose and form the two subgroups for this research. Millich et al. (1982) developed the IOWA Conners Teacher Rating Scale. The IOWA Conners Rating scale consists of two five-item scales designed to assess Inattention/Overactivity and Aggression/Defiance. The scales were created by identifying those items from the Conners Teacher Rating scale that correlated significantly with

either but not both empirically derived Hyperactivity or Aggressive factors that emerge from ratings of psychiatric chart material. This scale can also be completed by parents. Millich et al. (1982) developed normative data, internal consistency, and test-retest reliability for the scale.

Swanson and Taylor (in press) have developed Structured Interviews for the DSM-III-R. Two structured interviews, one with the parent and one with the child, are completed. These interviews are based on the DSM-III-R criteria for the diagnostic categories of ADHD, ODD, and Conduct Disorder. The interviews are designed to clarify these criteria resulting in more objective diagnoses.

Procedure

Auditory ERPs were recorded using a commercially available system (Biocomp) which included an Apple II computer for stimuli presentation, reaction time recording, averaging, printing, and scoring. Biocomp amplifiers and filters were used to modify the data, and this data was stored on diskettes for later analyses. Auditory ERP recording was based on the protocol at the University of California Irvine Department of Neurology for an oddball paradigm. Two auditory stimulus types were used in this paradigm: Stimulus 1 (rare) was an 885-Hz tone occurring 25 percent of the time and Stimulus 2 (common) was a 526-Hz tone occurring 75 percent of the time. The total time window was 1000 milliseconds (msec) with a prestimulus sample of 160 msec, and a poststimulus sample of 840 msec. Amplitude measurements were made for baseline-to-peak components relative to a constant objective baseline. Baseline (0 microvolts) was the average of the EEG over the time base. Two channels were used for data acquisition and recording corresponding to one active scalp electrode and one channel for Electrocculograph (EOG) which was used as an artifact assessment at a setting of 75 microvolts; if more than 10 sweep rejects occurred, the subject was excluded from the study. Fifty repetitions were recorded and averaged per condition per channel. The ERP components were recorded according to the Standard International 10-20 System electrode placement at the Cz location, referenced to linked left and right Mastoids with a ground on the right earlobe.

The subject diagnostic classifications were confirmed by expert rater consensus. The ERP scorer and recorder was blind to each child's classification group. The ERP procedure and Oddball task were explained and demonstrated to the subject according to printed instructions (Linden, 1988). The ERP recording occurred in a small, quiet room at the same time of day for each subject. Contact scalp location points were cleansed with Omni Prep abrasive solution. Silver Grass electrodes were applied using Grass EC2 electrode cream to the locations described above. The subject was instructed to lie down on an inclined examining table, close their eyes, and attempt to remain as still as possible, only moving their dominant hand thumb to push the RT button. Auditory ERPs were recorded until fifty sweeps were completed of both Stimulus 1 and 2, or until ten sweep rejects occurred. The latter was a criteria for exclusion from the study.

Results

Planned orthogonal comparisons were performed to assess subgroup differences with the ADHD clinical group, in addition to the usual comparisons of a normal control group to an ADHD clinical group. To accomplish this, two comparisons were made: 1) the control group was compared to the heterogeneous clinical ADHD group (the average of the ADHD and Mixed group), and 2) the two subgroups of ADHD cases (the pure ADHD and Mixed) were compared.

Using a one way ANOVA, the overall difference between the three groups for RT was not significant, however on an ANOVA comparing the three groups overall, the adjusted means for age for RT approached significance. In univariate ANOVAs, the control and clinical groups differed significantly

Table 1

Summary Table of Adjusted Means and Standard Errors of ERP Latencies and Reaction Time

Measures		P1	N1	P2	N2	P3	RT
Group							
Pure	M	70.4	125.6	191.1	255.2	318.1	733.5
N=21	SE	5.0	5.6	5.4	5.4	6.6	36.0
Mixed	M	69.1	120.6	182.5	250.6	315.8	728.2
N=24	SE	4.7	5.3	5.1	4.9	6.1	33.8
Control	M	71.9	115.4	181.4	233.2	297.6	613.5
N=14	SE	6.2	6.9	6.7	6.4	7.9	44.1

Summary Table of Adjusted Means and Standard Errors of ERP Amplitudes

Measures		P1	N1	P2	N2	P3
Group						
Pure	M	4.1	-10.7	14.4	-7.2	8.7
N=2	SE	0.8	1.4	1.7	1.8	1.5
Mixed	M	4.4	-6.5	12.2	-6.8	8.2
N=24	SE	0.8	1.3	1.6	1.6	1.4
Control	M	3.3	-7.4	12.1	-2.5	12.9
N=14	SE	1.0	1.7	2.1	2.1	1.9

from each other on four of the dependent measures: Reaction Time [F(1,55)=5.47, p=.02]; N2 latency [F(1,54)=7.07, p=.01]; P3 latency [F(1,54)=4.58, p=.04]; and P3 amplitude [F(1,54)=4.49, p=.04]. These effects are consistent with the literature that has shown the heterogeneous ADHD group to be slower in response to auditory stimuli, as reflected by RT as well as the late components of the ERP (see Table 1 and Figure 1). The second orthogonal comparison yielded a significant main effect of Subgroup (pure ADHD vs. Mixed) on N1 amplitude [F(1,41)=4.28, p=.04], an early component of the ERP (see Figures 1 and 2).

A one way analysis of variance with age as a covariate was performed to assess effects of Group (ADHD, Mixed, Control), Age (as a continuous variable from 5 to 12 years), and the interaction of these two factors (by comparisons of age trends across the groups). Developmental age effects were assessed comparing the slopes of each of the three groups on scatter plots of each of the ERP variables and RT regressed against age. The differences between slopes of the three groups was assessed using ANOVAs. When an inequality between the slopes occurred, the differences between the group's slopes and correlations were compared.

The age trends differed significantly for the two ADD subgroups on two early components of the ERP: N1 latency [F(1,41)=5.28, p=.03] and P2 latency [F(1,41)=7.05, p=.01] (see Figures 3 and 4). The pure ADHD group

Figure 1
Plot of Group Means for Diagnostic Groups
Baseline to Peak Amplitude vs. Latency

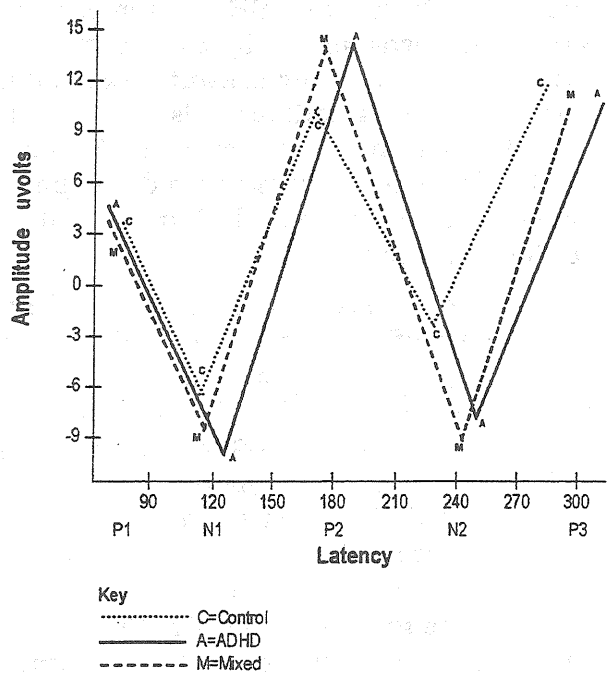


Figure 2
N1 Amplitude Across Age for ADHD, Mixed, & Control Groups

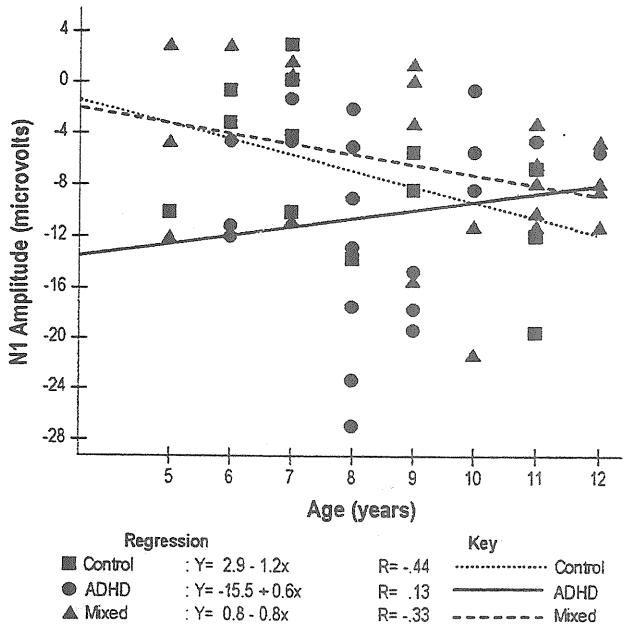


Table 2

Regression Coefficients (slopes) for ERP Latencies

Measure	P1	N1	P2	N2	P3
Group					
ADHD	0.47	-10.54	-8.83	-5.25	-5.23
Mixed	-1.71	-1.31	1.56	1.35	-0.74
Control	2.88	1.49	0.52	1.79	4.37

Regression Coefficients for RT & ERP Amplitudes

Measure	RT	P1	N1	P2	N2	P3
Group						
ADHD	-39.3	-0.34	0.59	3.81	0.21	2.29
Mixed	-53.7	-0.24	-0.84	1.93	-0.26	0.26
Control	-47.7	-0.62	-1.22	0.14	0.54	0.28

Figure 3
Scatter Plot of N1 Latency vs. Age
for Diagnostic Groups

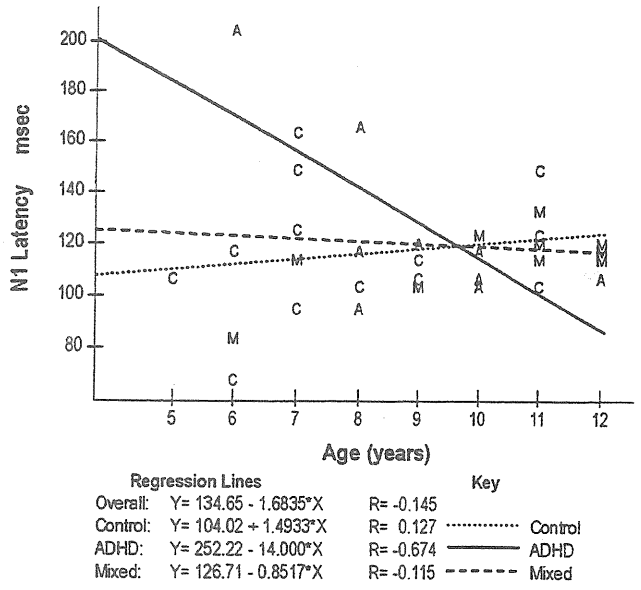
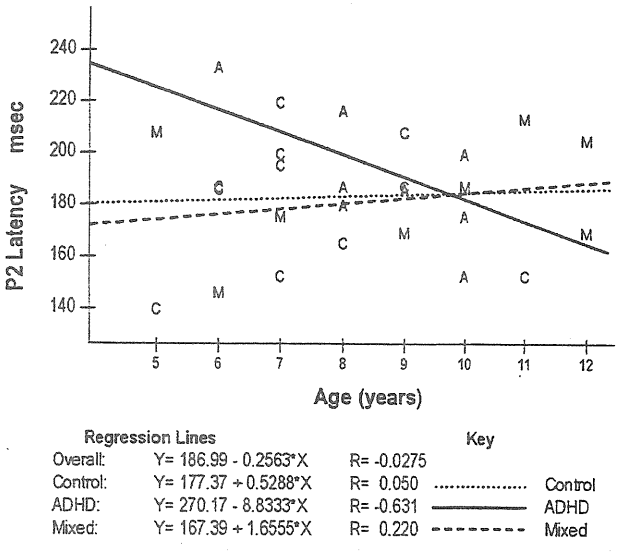


Figure 4
Scatter Plot of P2 Latency vs. Age
for Diagnostic Groups



had steeper (more negative) slopes for the age-N1 and age-P2 regression functions (see Table 2) than the Mixed subgroup or the control group. The young pure ADHD cases had significantly longer than normal ERP latencies of the early components (N1 and P2), but by age 12 this difference had dissipated. As shown in Figures 1 and 2, and Table 1, a similar, but non-significant developmental trend for ERP latencies and amplitudes was shown by the Control and Mixed groups. Non-significant longer latencies and higher amplitudes also occurred for the ADHD group for the other ERP components. This pattern suggests a developmental delay in the pure ADHD group, but not in the Mixed group.

Finally, a 3 (group) X 2 (age) ANOVA produced a significant age effect which differentiated the three groups on RT. An age main effect occurred for RT, with the RT of the younger subjects (5-9 years) being significantly slower than the older group (10-12 years); this is an expected maturational difference (see Table 3). However, there was no significant age effect which differentiated between the groups on RT. Another significant main age effect occurred for P2 amplitude, with the younger group being smaller than the older group (see Figure 5). An interaction effect between age and group occurred for N1 amplitude: [$F(2,53)=5.86$, $p<.00$]; the younger ADHD group had larger N1 amplitudes and the older ADHD group had smaller N1 amplitudes than both the Control or Mixed groups (Figure 2). An interaction effect also occurred for P2 latency: [$F(2,53)=3.96$, $p=.02$]; the older Mixed and the younger ADHD groups had longer than normal P2 latencies (Figure 4).

Discussion

The results of this electrophysiological study support the validity of the subgroups of disruptive behavior disorders and hyperactive children. More specifically, when an aggressive factor is taken into consideration, the children having ADHD without aggression were found to be abnormal physiologically in terms of their ERP's and RT's compared to a group having ADHD and aggressive behavior (Mixed), and a normal control group. These results become even more pronounced when developmental age effects are examined.

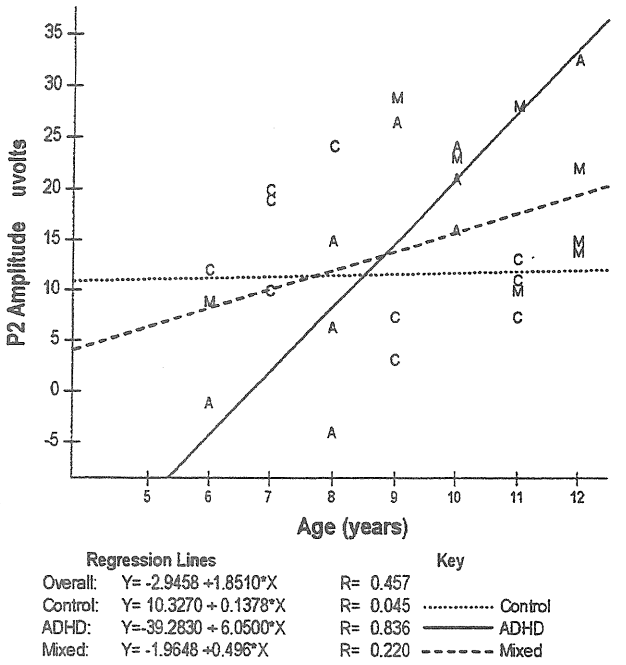
Table 3
Summary Table of Means and Standard Deviations for Age x Group Comparisons for RT and Amplitude

Measure		RT	P1	N1	P2	N2	P3
Group							
Y Contr	M	680.2	3.7	-5.6	11.4	-3.7	11.9
N = 10	SD	197.5	5.8	4.9	7.6	7.8	5.5
Y ADHD	M	785.2	4.4	-12.2	11.9	-7.2	6.9
N = 16	SD	133.5	4.1	7.2	10.0	7.5	7.5
Y Mixed	M	793.1	4.9	-4.4	9.5	-7.5	8.4
N = 13	SD	206.7	3.1	5.9	8.0	7.9	7.5
0 Contr	M	509.0	2.7	-10.9	11.7	0.5	14.6
N = 4	SD	187.4	4.8	6.9	3.2	4.3	4.1
O ADHD	M	608.6	3.6	-5.1	21.0	-7.3	13.8
N = 5	SD	101.6	3.8	3.0	8.2	6.4	10.4
O Mixed	M	610.5	3.4	-9.5	16.9	-5.9	8.5
N = 11	SD	200.8	1.5	4.7	6.6	10.2	5.1

Summary Table of Means and Standard Deviations for Age x Group Comparisons for Latency

Measure		P1	N1	P2	N2	P3
Group						
Y Contr	M	70.4	114.8	184.0	234.4	296.4
N = 10	SD	22.1	22.2	25.1	25.0	25.0
Y ADHD	M	69.8	132.5	198.0	260.5	324.5
N = 16	SD	24.9	37.1	31.0	28.6	30.8
Y Mixed	M	71.1	120.6	175.4	249.2	322.5
N = 13	SD	28.2	20.6	19.7	27.3	32.9
O Contr	M	76.0	120.0	176.0	230.0	301.0
N = 4	SD	37.2	20.9	16.0	7.7	26.8
O ADHD	M	72.8	105.6	169.6	239.2	299.2
N = 5	SD	4.4	8.8	25.6	15.6	12.1
O Mixed	M	66.5	118.5	190.2	252.4	307.6
N = 11	SD	12.0	12.2	12.0	14.7	29.6

Figure 5
Scatter Plot of P2 Amplitude Baseline-Peak vs. Age for Diagnostic Groups



Specifically, in comparison to the control group, both the pure ADHD and Mixed groups had slower responses on the late ERP components (N2 latency, P3 latency) and RT, suggesting delays in stimulus evaluation or motor components of information processing (Klorman, Brumaghim, Salzman, & Strauss, 1988). However, in the subgroup comparison, only the ADHD group had abnormal early components suggesting sensory or attentional abnormalities. The slower RT for the pure ADHD and Mixed groups supports the findings of Loiselle et al. (1980), and Holcomb, Ackerman, and Dykman (1985).

Sergeant and Van der Meere (1988) have suggested that the unitary view of "arousal" be broken down into two separate processes of sensory arousal and motor activation. Swanson and Taylor (in press) have suggested that ADHD children may be over-aroused and underactivated. Our ERP data was consistent with this theoretical view. Both the pure ADHD and Mixed groups may be considered low in terms of the dopamine related motor activation process. This is manifested as extended RT and delayed latencies of the late components of ERP. However, only the pure ADHD group may be considered to be high in terms of the noradranergic related sensory arousal process, which is manifested by high amplitudes for the early components of the ERP.

Moreover, these electrophysiological abnormalities suggest that the younger (5-9 year old) ADHD children's brain responses are similar to those of even younger children, and support the notion that these children have a "maturational lag." These developmental results support the previous research (Buchsbaum & Wender, 1973; Satterfield & Brawley, 1977) findings that younger hyperactive children were the deviant group on ERP variables. Perhaps the ADHD childrens' brain mechanisms change more drastically with increasing age.

Taken together, these analyses of subgroups and developmental trends indicate that the early components of the ERP differentiate the clinical (ADD) subgroups. The late components and RT do not differentiate the clinical subgroups, even though both ADD subgroups are significantly different from the normal controls on these measures.

In terms of future research implications, it seems clear that both distinct subgroups and age effects should be included and contolled for in any studies of hyperactive (ADD) or disruptive behavior disorder children. Thus, one must assess both subgroup and developmental effects in ERP and EEG research and in EEG Biofeedback treatment of hyperactivity or ADD.

Treatment Implications

EEG Biofeedback treatment of hyperactive (ADD) children has been performed by Lubar (1976, 1979, 1984) and Tansey (1985, 1990) among others. These researchers trained ADD and Learning Disabled children to increase their abnormally deficient

Beta and Sensorimotor Rhythm (SMR) EEG frequencies while simultaneously decreasing their abnormally high Theta EEG frequency. The EEG findings of low SMR/Beta and high Theta seem to correlate with our findings of high amplitude early components and slow latency late components. Since the pure ADD children appear to have motor underactivation and sensory overarousal, the EEG Biofeedback which activates the SMR/Beta frequencies (related to motor activation and dopamine production) and decreases the Alpha/Theta frequencies (related to sensory arousal and noradranergic production) may directly correct these abnormalities and lead to attentional and behavioral improvement.

These treatments have resulted in not only significant reductions in hyperactive and disruptive behaviors, but also improvements in academic performance and even IQ. The EEG Biofeedback treatment should focus specifically on younger ADHD children, whose electrophysiological abnormalities need the greatest correction.

Finally, in terms of treatment, it may be possible to use Biofeedback to alter the RT and ERP abnormalities of the ADHD children directly as others have done with the EEG. Biofeedback of ERP late components should be developed with goals of shortening latencies and decreasing amplitudes, thus possibly normalizing arousal and information processing. Based on our findings with these two subgroups, some treatment implications are warranted. Recent research in EEG Biofeedback (Lubar, 1976, 1979, 1980; Linden, 1996; Tansey, 1985, 1990) indicates this treatment may be effective for children who have ADHD and ADD. Future research needs to decipher the success of EEG Biofeedback using various subgroups and age groups of ADHD children.

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Richard Gevirtz, Ph.D. is a professor at the California School of Professional Psychology in San Diego. He has published several research studies in the biofeedback area.

Robert Isenhart, B.A. developed the event-related potentials equipment used in this study.

Todd Fisher, B.A. developed the statistics and graphs for this study.

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