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Sensory Modulation of Auditory Stimuli in Children with Autism and Receptive Developmental Language Disorder: Event-Related Brain Potential Evidence[1]

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Three groups of age- and PIQ-matched children (Autism, Receptive Developmental Language Disorder, and normal controls) participated in two event-related brain potential (ERP) experiments. Each of these experiments was aimed at evaluating whether either of the two clinical groups of children demonstrated abnormalities in two auditory ERP components, N1 and P2, which are known to be dependent on stimulus characteristics (frequency, intensity, and probability), and believed to be generated within primary and secondary cortex. Results of Experiment 1 provide partial support for the idea that both clinical groups failed to fully process changes in stimulus intensity as indexed by the N1 component. Results are discussed in reference to potential abnormalities in serotonergic regulation of auditory cortex.

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INTRODUCTION

Kanner (1943) noted that children with early infantile autism had deviant language and were sometimes unusually reactive to loud noises. Subsequent investigators noted that children with autism may have a faulty capacity to effectively modulate sensory input (James & Barry, 1980; Kootz, 1982; Ornitz & Ritvo, 1968). Furthermore, in autism there may be significant individual differences in how sensory input is regulated (i.e., hyper- and hyposensitivity to environmental stimuli; Kinsbourne, 1987).

However, if individuals with autism are abnormal in their capacity to regulate sensory input, the evidence of specific neuropathology in a system responsible for such regulation is not clear. For example, in the auditory modality there is strong evidence that nonretarded individuals with autism and Receptive Developmental Language Disorder (RDLD) demonstrate normal auditory brainstem evoked responses (ABERs, Courchesne et al., 1985; Courchesne, Lincoln, Yeung-Courchesne, Elmasian, & Grillon, 1989). These early auditory ERPs (present during the first 10 msec following an auditory stimulus) suggest that the initial, primarily subcortical, neural generators of the ABER are intact.

Midlatency auditory evoked responses (ERPs present between 10 and 80 msec) have also been found to be normal in people with autism and RDLD (Courchesne et al., 1989). Auditory midlatency responses are believed to be generated in the thalamus, thalamatic radiations, and auditory cortex. This suggests that thalamic nuclei and radiations are intact as well as auditory cortex subserving such midlatency responses.

There has, however, been substantial evidence of abnormal late auditory ERPs in people with autism. The P300 or P3b component of the ERP (present between approximately 290 to 550 msec following the detection of an auditory target stimulus) has consistently been found to be of small amplitude in children, adolescents and adults with autism (Courchesne, Galambos, & Lincoln, 1984, 1985, 1987, 1989; Dawson, Courchesne et al., Finley, Phillips, Galpart, & Lewy, 1988; Lincoln, Courchesne, Harms, & Allen, 1993). It is unlikely that this abnormality of the auditory P3b is due to the presence of impaired language skills because it is not found in children, adolescents, or adults with RDLD (Courchesne et al., 1989; Lincoln et al., 1993). This late positive component of the ERP is not dependent on physical characteristics of the stimulus being detected (i.e., intensity and frequency), but rather on stimulus probability, meaningfulness and task relevance (Johnson, 1992). Thus, it is unlikely that the abnormally small auditory P3b found in people with autism is due to neuropathology associated with the faulty regulation of the physical characteristics of incoming sensory stimuli. However, it could be influenced by the degree to which stimulus probability and task relevance impact earlier steps in information processing following the midlatency potentials and prior to the P300.

There are two well-studied ERP components that fall within such latency window. These two late ERP components, N1 (N100) and P2 (P200), are largest in amplitude at the center of the scalp (Cz) and are quite sensitive and dependent on *both* the attention directed toward task-relevant stimuli of varying probabilities and the physical qualities of auditory stimuli (i.e., intensity and frequency) (Adler & Adler, 1989, 1991; Adler, Adler, Schneck, & Armbruster, 1990; Picton, Woods, & Proulx, 1978). Picton et al. (1978) reported N1 to be fairly stable in amplitude up to 2 kc/sec and then fall off significantly in amplitude to higher frequencies. P2 was reported to increase in frequency between 1 kc/sec and 8 kc/sec. N1 and P2 were also both reported to increase in amplitude as stimulus intensity increased.

Moreover, these two components have been studied in people with autism, but the results have been inconsistent regarding abnormalities of their magnitude and latency (Adams et al., 1995; Bruneau, Garreau, Roux, & LeLord, 1987, 1989; Courchesne et al., 1984, 1985, 1989; Dawson et al., 1988; Novick, Kurtzberg, & Vaughan, 1979; Novick, Vaughan, Kurtzberg, & Simson, 1980; Oades, Walker, Geffen, & Stern, 1987; Prichard, Raz, & August, 1987). These two components are quite likely generated within the superior temporal plane and lateral temporal gyri of primary and secondary auditory cortex (Makela & Hari, 1990; Naatanen & Picton, 1987; Vaughan & Arezzo, 1988; Wood et al., 1984). Furthermore, Hegerl and Juckel (1993) presented evidence that serotonergic systems may play a crucial role in modulating the cortical processing of sensory thalamocortical input, and that "serotonergic innervation of primary auditory cortex modulates the intensity dependence of the auditory evoked N1/P2 component" (p. 183). This may be consistent with Bruneau et al.'s (1989) finding that prior to treatment with fenfluramine 6 of 13 children with autism had lower serotonin levels.

Only two ERP studies report the effects of varying stimulus intensity on N1 and P2 (Bruneau et al., 1987, and Pritchard et al., 1987). Unfortunately, four of the five control subjects in the Prichard et al. study had DSM-III diagnoses of conduct disorder, making group differences difficult in interpret.

Bruneau et al. (1987) measured the average voltage from stimulus onset to 250 msec. This included the P1, N1, and P2 ERP components. They reported that autistic subjects did not differ from control subjects across varying stimulus intensities (40, 50, 60, 70, and 80 dB SPL). However, they did report that there was more variability in the autistic AEP amplitudes than in controls. They suggested a hypothesis of a strong stimulus intensity control mechanism in the pathology of a subgroup of subjects with autism because that subgroup of autistic subjects had small AEP voltages at higher intensity levels.

RDLD is another early childhood disorder in which language fails to develop normally while nonverbal cognitive and intellectual abilities are relatively spared and better developed (Allen, Lincoln, & Kaufman, 1991; Lincoln et al., 1988, 1993, in press). Children with RDLD do not have the degree or type of social impairment as do children with autism. In a small percentage of cases, these diagnoses can be confused until the symptoms specific to each disorder become more evident. RDLD children have been hypothesized to have an impaired ability to process rapid acoustic information (Tallal et al., 1973a, 1973b; Tallal, Stark, Kallman, & Mellits, 1981), and encode auditory information in short-term memory (Lincoln, Dickstein, Courchesne, Elmasian, & Tallal, 1992).

Courchesne et al. (1989) did not find adolescents and adults with RDLD to be different than control subjects in either their N1 or P2 amplitudes and latencies. Adams, Courchesne, Elmasian, and Lincoln (1987) reported that RDLD adolescents and adults had a larger P2 amplitudes than control subjects in a recovery cycle experiment. Their data suggested that such amplitude differences at 1.2- and 5-sec ISIs could not be fully accounted for by a problem of processing rapidly changing acoustic information. They described how the RDLD subjects must have some "fundamental auditory processing abnormality across a wide temporal range" (p. 583). However, there was no effort to manipulate intensity in either of the above studies.

To determine whether individuals with autism could regulate their attention and sensory responsiveness to auditory stimuli, we conducted two experiments. In the first experiment we compared the ERPs in autistic, RDLD, and normal control children to 1000-Hz and 3000-Hz tones of two different intensities to determine (a) whether group differences in N1 and P2 amplitude and latency would be observed, and (b) whether N1 and P2 would change in amplitude as a function of stimulus intensity or frequency. In the second experiment we compared these same three groups of children to determine how variations in stimulus probability (70 vs. 30%) would affect N1 and P2 amplitudes and latencies. Abnormal modulation of the N1 and P2 amplitude and latency in children with autism and RDLD would support an interpretation that the underlying generators of these components in auditory cortex are impaired. It would also support the idea that the serotonergic system supporting these generators in auditory cortex might be abnormal, at least in some individuals. Further, it would support the idea that individuals with autism and RDLD may process sensory information abnormally in the auditory modality. This could help explain their inconsistency in responding to auditory information and the failure to develop auditory-dependent language skills in a normal manner. Further, because autism and RDLD are different disorders in which language fails to develop normally, it will be possible to determine how auditory sensory problems, if any, differ between these two groups of children.

EXPERIMENT 1

Methods

Subjects

All subjects had to be between 8 and 14 years of age. Ten children with autism, 10 children with RDLD, and 10 normal control children initially participated in this experiment. All subjects with autism were identified by major state agencies. Each of these children were clients of the San Diego Regional Center (a state agency providing services to developmentally disabled persons) on the basis of autism. In addition, all of these children were in special education classes through the public schools for severely handicapped and/or language-handicapped children. None of the children with autism were institutionalized or living away from their family. Upon referral from these agencies all subjects had their histories and records reviewed, and were independently evaluated in face-to-face interviews, including interviews with their parents. All of the children with autism were diagnosed by the senior author and M.A., and met the full criteria for Pervasive Developmental Disorder (Infantile Autism) according to the DSM-III-R criteria. They all also fell within the Moderate to Severe range of autism on the Childhood Autism Rating Scale (Schopler, Reichler, & Renner, 1988). Aside from their autism, all of these children had normal medical examinations which included neurologic assessment, fragile × screening, EEG, ABER, and metabolic studies. All medical and laboratory studies were normal. None of these children were taking medication. One of these children was unable to complete Experiment 1 because of excessive movement which resulted in EEG artifact.

All children with RDLD received special education services through the public schools for language-handicapped children prior to kindergarten. All lived at home. All of the children with RDLD were diagnosed by the senior author and M.A. They met the full criteria for Developmental Receptive Language Disorder according to the DSM-III-R criteria. Each of these children had a history of early receptive language impairment and normal hearing. All were being seen by speech pathologists prior to 4 years of age with demonstrated severe delays in receptive and expressive language development. All of these children had normal medical examinations which included neurologic assessment. None had a concurrent DSM-III-R Axis I disorder, PDD, or was taking medication. Furthermore, the language impairments were not attributed to acquired aphasia, impaired oral–motor functioning, bilingualism, dialectical speech patterns, or lack of familiarity with the English language. All were able to complete Experiment 1.

The normal control children had no DSM-III-R Axis I or Axis II disorder. All were in regular public school classes. None of these children were ever in special education classes. They all had normal hearing (as measured by brainstem audiometry) and medical histories free of any serious injuries or hospitalizations. They all had regular routine pediatric care. None were taking medication. All of the normal control children completed the experiment without difficulty.

In addition, all children completed an extensive battery of diagnostic audiologic, psychological, and language tests. These tests included the Wechsler Intelligence Scale for Children-Revised (WISC-R; Wechsler, 1974), Developmental Test of Visual Motor Integration-Revised (VMI; Beery, 1984), Wide Range Achievement Test-Revised (WRAT-R, Jastak & Wilkinson, 1984), Peabody Picture Vocabulary Test-Revised (PPVT-R; Dunn & Dunn, 1981), Clinical Evaluation of Language Functions-R (CELF-R, 1987), and Test of Language Development-2 (TOLD-2, 1988). Results of these examinations are reported in Lincoln et al. (1993). To be included in the study all subjects had to have normal hearing as measured by brainstem audiometry and a WISC-R Performance IQ greater than 70. The RDLD children had to have Performance IQs 15 or more points greater than their receptive vocabulary scores on the PPVT-R. In addition obtained scores from multiple standardized measures of basic language functions (i.e., CELF-R and TOLD-R) had to be 1.5 standard deviations below average in at least one or more of the following areas of language development: morphology, syntax, semantics, and pragmatics. The normal control subjects all had to have PPVT-R standard scores, WRAT-R standard scores, and VMI standard scores within 1 standard deviation of their WISC-R Performance IQ score. The other behavioral and language tests were used to further characterize all of the Children's behavioral performance.

Procedures

EEG was recorded from Beckman Ag2 + Cl electrodes placed at Fz, Cz, Pz, Oz, LoE (below the right eye), Fp2+ (placed midway between Fp2 and F8), F3, F4, C3, C4, P3, and P4 according to the 10–20 system. Electrodes were referenced to the right mastoid and grounded behind the left ear. EEG was amplified by a Grass Model 12 Neurodata Acquisition System with an EEG band pass of .01 and 100 cycle/sec. EEG was digitized by a computer. Trials with eye blink, muscle artifact, or eye movements were detected and excluded from ERP averages by computer algorithms. Averages contained at least 25 trials.

Two ERP components, N1 and P2, were operationally defined and measured in this experiment. N1 was defined as the largest negative peak 80 to 150 msec poststimulus onset at Cz. P2 was defined as the largest positive peak 130- to 240-msec poststimulus onset at Cz. The additional electrode placements were only used to visually verify the computer's accuracy in identifying the correct peak amplitude as either N1 or P2. In all cases the correct peak was identified by the computer.

Subject Instructions and Stimuli

Subjects were instructed to listen to randomly presented tones which differed in frequency and intensity (1000 Hz, 60 dB SPL, $p = .25$; 1000 Hz, 70 dB SPL, $p = .25$; 3000 Hz, 63 dB SPL, $p = .25$; and 3000 Hz, 73 dB SPL, $p = .25$). Tones were presented in blocks of 200 tones with 2-second ISIs. Each subject heard at least 100 of each tone.

Results: Experiment 1

N1 and P2 Amplitude

Table I shows mean N1 peak amplitudes and standard deviations for the autistic, RDLD, and control subjects. Differences among the three groups in N1 amplitude were not statistically significant, $F(2, 26) = 1.0$, $p = .38$. There was, however, a tendency for N1 to increase in negativity with greater stimulus intensity, $F(2, 26) = 3.79$, $p = .06$. This was not the case for frequency, and there was not a significant Intensity × Frequency interaction or Intensity × Frequency × Group interaction. A supplemental analysis of N1 showed that there was great individual variability of absolute N1 amplitude among subjects in all three groups (Autistic range: -19.1 to -.97 μV; RDLD range: -28.24 to 2.28 μV; and Control range: -21.19 to 2.01 μV). Within subject variability was smaller (Autistic range: -10.6 to -18.31 μV; RDLD range: -10.65 to -0.7 μV; Control range: -21.19 to -5.31 μV). However, unlike the children with autism or RDLD the control children did demonstrate a clear increase in N1 amplitude to increases in stimulus intensity, $F(1, 9) = 8.90$, $p = .015$ (see Figure 1).

Table I. Experiment 1: N1 and P2 Peak Amplitudes at Cz for Autistic, RDLD, and Control Subjects

			Autistic		RDLD		Control	
Intensity		Hz	*M*	*SD*	*M*	*SD*	*M*	*SD*
N1	High	1000	-8.97	6.84	-12.31	6.92	-9.94	6.49
N1	High	3000	-10.48	5.74	-11.53	7.74	-9.5	5.26
N1	Low	1000	-8.19	4.63	-11.76	6.94	-6.92	4.09
N1	Low	3000	-9.86	6.67	-11.94	6.08	-7.47	4.28
P2	High	1000	12.68	6.15	13.63	11.82	15.43	8.46
P2	High	3000	10.39	6.84	13.36	11.19	16.23	7.96
P2	Low	1000	9.53	4.95	12.37	10.51	14.17	5.94
P2	Low	3000	7.73	3.74	9.08	6.41	11.42	6.12

Table I also shows mean P2 peak amplitudes and standard deviations for autistic, RDLD, and control groups. As was the case for N1 amplitude, there were statistically significant differences in P2 peak amplitudes among the three groups. However, increasing stimulus intensity resulted in a statistically significant increase in P2 peak amplitude for all three groups, $F(1, 26) = 13.55$, $p = .001$. Furthermore, decreasing stimulus frequency resulted in a statistically significant increase in P2 peak amplitude, $F(1, 26) = 4.75$, $p = .04$. There were no statistically significant interactions between intensity and frequency on P2 peak amplitude or statistically significant Intensity × Frequency × Group interactions on P2 peak amplitude (see Figure 1).

N1 and P2 Latency

Table II shows mean N1 peak latencies and standard deviations for the autistic, RDLD, and control subjects. There were no statistically significant differences among the three groups in N1 latency, $F(2, 26) = 0.74$, $p = .49$. There were also no significant main effects on N1 latency for either frequency, $F(1, 26) = 1.56$, $p = .22$, or intensity, $F(1, 26) = 0.44$, $p = .56$. There was, however, a significant Frequency × Intensity interaction for N1 latency, $F(1, 26) = 4.82$, $p = .04$ (see Figure 1).

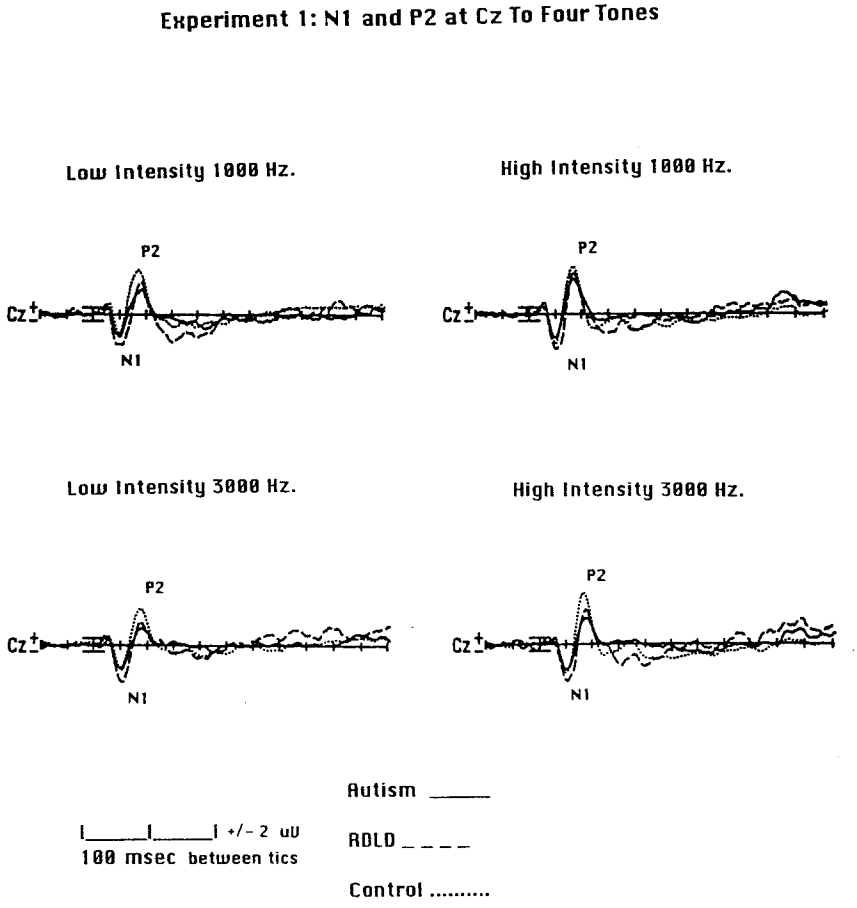

Fig. 1. ERPs at electrode site Cz to the four tones of Experiment 1.

Table II also shows mean P2 peak latencies and standard deviations for the autistic, RDLD, and control subjects. There were no statistically significant differences among the three groups in P2 latency, $F(2, 26) = 0.23$, $p = .80$. There was, however, a significant main effect of frequency on P2 latency, $F(1, 26) = 12.05$, $p = .0018$. The latency of P2 was longer at higher frequencies for all three groups. There were no significant main effect of intensity on P2 latency, $F(1, 26) = 0.94$, $p = .34$ or significant interaction between stimulus intensity and frequency on P2 latency, $F(1, 26) = 0.01$, $p = .91$ (see Figure 1).

Table II. Experiment 1: N1 and P2 Peak Latencies at Cz for Autistic, RDLD, and Control Subjects

			Autistic		RDLD		Control	
Intensity		Hz	*M*	*SD*	*M*	*SD*	*M*	*SD*
N1	High	1000	99.2	21.4	103.5	20.7	95.9	8.0
N1	High	3000	101.6	20.0	100.9	14.7	93.3	8.3
N1	Low	1000	99.2	21.3	101.7	20.2	93.4	8.7
N1	Low	3000	106.8	20.4	103.6	19.2	95.9	7.7
P2	High	1000	171.1	22.5	159.3	18.5	167.1	12.2
P2	High	3000	175.7	30.0	171.8	20.3	170.2	11.7
P2	Low	1000	169.4	32.4	169.2	20.0	166.2	12.6
P2	Low	3000	177.2	27.8	175.3	22.1	170.6	19.3

EXPERIMENT 2

Methods

Subjects

The same subjects participated in Experiment 2 that participated in Experiment 1 with the exception of one child with autism and one child with RDLD who could not complete Experiment 2. All of the normal control children completed Experiment 2.

Procedures

The recording procedures were identical to those described in Experiment 1.

Subject Instructions and Stimuli

Two auditory stimuli were presented to subjects: 1000 Hz and 2000 Hz computer-generated triangle waves (68 dB SPL). Each stimulus was 50 msec in duration. The interstimulus interval was 2 sec. The 1000 Hz and 2000 Hz stimuli were randomly ordered. They were presented in blocks of 100 with a rest period of at least 1 minute between consecutive blocks.

Children with autism, children with RDLD, and normal control children had their ERPs recorded during an auditory 70%–30% odd-ball stimulus paradigm under two different conditions. This paradigm was designed as follows: in the *Response* condition, children responded to each frequent stimulus (p = .70) by pressing one button and each infrequent stimulus (p = .30) by pressing another button. The 1000 Hz and 2000 Hz tones were counterbalanced across all subjects with respect to being the frequent or infrequent stimulus. Likewise, the hand used to press each button was also counterbalanced across all subjects. In the *No-response* condition children simply listened to stimuli which were identical to the stimuli presented in the Response condition.

Results: Experiment 2

Behavioral Performance During ERP Experiment

Response Accuracy. During the Response condition of the experiment, autistic children correctly responded to 75% (SD = 0.21) of the frequent stimuli and 74 (SD = 0.21) of the infrequent stimuli, RDLD children correctly responded to 56% (SD = 0.17) of the frequent stimuli and 61% (SD = 0.13) of the infrequent stimuli. The normal control children performed in a similar manner to the autistic children. They correctly responded to 76% (SD = 0.15) of the frequent stimuli and 76% (SD = 0.15) of the infrequent stimuli. In spite of the seemingly poorer performance of the RDLD children compared to both autistic and normal control children, the difference was not significant, $F(2, 24) = 3.09$, p = .06.

Reaction Time (RT). The three groups of children did not differ significantly from each other in their mean RTs to frequent and infrequent stimuli, $F(2, 24) = 0.34$, p = .72. There was not a Group × Probability interaction on RT, $F(2, 24) = 0.10$, p = .91 or a main effect of probability on RT, $F(1, 24) = 2.43$, p = .13.

N1 and P2 Amplitude and Latency

In the No-response condition all three groups of children produced clear and well-defined N1 and P2 waves to both frequent and infrequent stimuli which were largest at Cz (see Table III). In the Response condition all three groups of children produced clear and well-defined N1 and P2 waves to both frequent and infrequent stimuli which were largest at Cz (Table III).

Table III. Experiment 2: Peak Amplitudes and Latencies as a Function of Condition and Stimulus Probability

		Autistic		RDLD		Control	
Wave	Condition	*M*	*SE*	*M*	*SE*	*M*	*SE*
N1	Task 70%	-8.5	2.4	-14.9	2.3	-5.4	1.5
		96.0	6.3	104.3	8.0	89.1	2.0
N1	Task 30%	-8.7	2.2	-12.9	2.0	-5.1	1.2
		101.1	9.6	95.5	7.4	90.6	3.9
N1	No task 70%	-9.6	2.1	-14.4	1.9	-8.2	1.8
		103.7	8.4	100.2	7.6	94.3	3.0
N1	No task 30%	-10.7	1.9	-15.6	1.9	-9.9	1.4
		102.7	6.7	105.3	6.6	93.2	2.9
P2	Task 70%	8.6	2.1	14.6	3.8	16.2	2.7
		172.6	6.4	175.9	9.1	165.8	2.8
P2	Task 30%	12.7	2.1	14.6	3.8	16.2	2.7
		163.3	6.4	166.9	7.3	166.8	2.6
P2	No task 70%	9.7	2.2	16.1	3.9	12.6	1.7
		167.3	5.9	174.6	4.4	167.4	4.0
P2	No task 70%	8.9	2.2	15.3	3.7	12.7	2.3
		170.0	5.7	176.3	5.7	170.9	3.2

Figure 2 shows N1 amplitudes at Cz as a function of condition and probability. There was a significant group effect on N1, $F(2, 24) = 5.02$, $p = .015$. Pairwise comparisons showed that the RDLD children had a significantly larger N1 compared to normal control children, $F(1, 24) = 9.72$, $p = .005$. The difference between children with RDLD and autism was nearly significant, $F(1, 24) = 4.19$, $p = .052$, with autistic children also having a smaller N1 than children with RDLD. There was a significant Condition × Probability interaction on N1, $F(1, 24) = 8.98$, $p = .006$, but not a significant Group × Condition × Probability interaction.

Figure 3 shows N1 latencies as a function of condition and probability. Although the N1 latencies were similar in autistic children and normal control children, they differed with respect to the RDLD children. There was a significant Group × Condition × Probability interaction on the latency of N1, $F(2, 24) = 5.05$, $p = .015$; RDLD vs. autistic: $F(1, 24) = 8.46$, $p = .0077$; RDLD vs. normal control: $F(1, 24) = 6.54$,

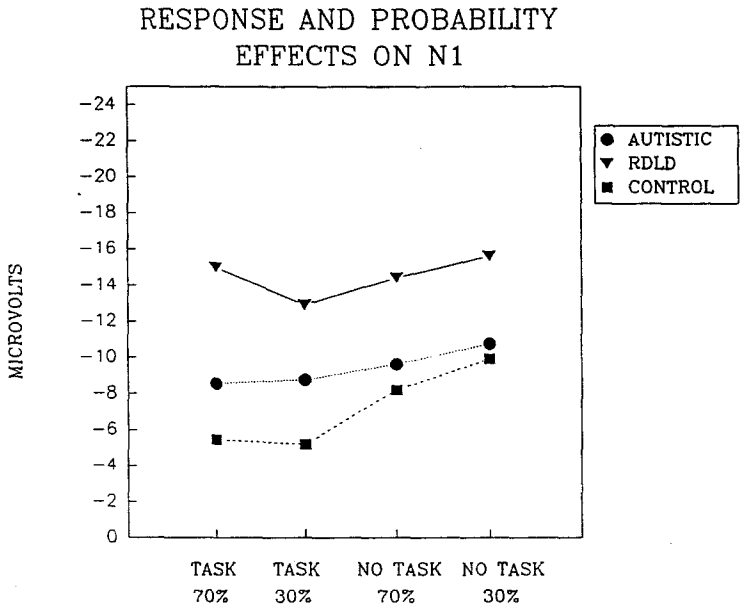

Fig. 2. The amplitude of N1 as it varies under conditions of task demand (Task = button press to high frequency and low frequency tone (either 1000 Hz or 2000 Hz), No Task = listen only to high frequency and low frequency tone) and stimulus probability $p = .70$ or $p = .30$.

$p = .017$). N1 latency tended to increase to the infrequent stimuli in the Response condition and remain level across frequent and infrequent stimuli in the No-response condition for autistic and normal control children. For RDLD children N1 latency decreased to the infrequent stimuli in the Response condition and increased to the infrequent stimuli in the No-response condition.

Figure 4 shows P2 amplitudes at Cz as a function of condition and probability. There was no significant group effect on P2, $F(2, 24) = 1.27$, $p = .30$. There was, however, a significant Condition × Probability interaction on P2 amplitude, $F(1, 24) = 6.34$, $p = .019$, but no significant Group × Condition × Probability interaction.

Figure 5 shows P2 latencies as a function of condition and probability. There was no significant group effect on P2 latency, $F(2, 24) = .51$, $p = .61$. There was, however, a nearly significant Condition × Probability interaction, $F(1, 24) = 4.25$, $p = .0504$.

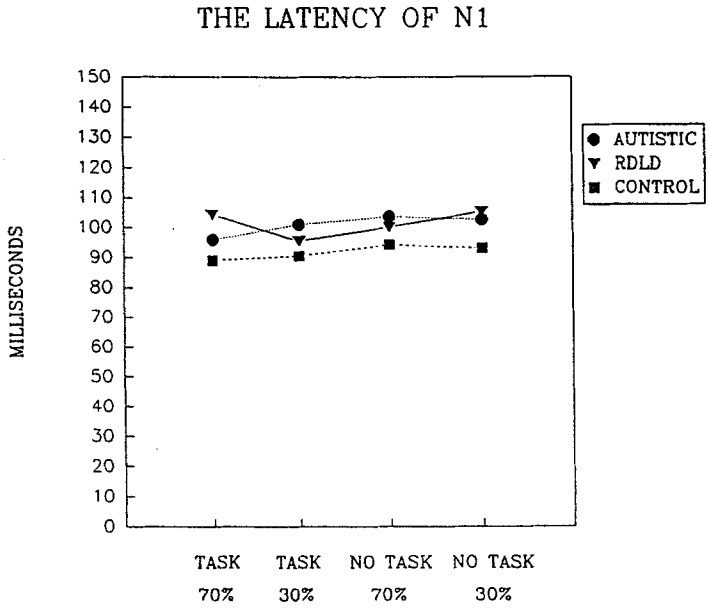

Fig. 3. The latency of N1 as it varies under conditions of task demand (Task = button press to high frequency and low frequency tone (either 1000 Hz or 2000 Hz), No Task = listen only to high frequency and low frequency tone) and stimulus probability $p = .70$ or $p = .30$.

DISCUSSION

Two ERP components, N1 and P2, sensitive to the attention directed toward task-relevant stimuli and changes of stimulus intensity and frequency were essentially similar in absolute amplitude and latency for the three groups of children studied. However, unlike control children, children with autism and RDLD did not show an increase in N1 amplitude to increases in auditory stimulus intensity. Furthermore, RDLD children showed abnormally large N1 components during attention-directed task conditions. This was not true of absolute P2 amplitude. All three groups of children demonstrated increased P2 amplitudes to auditory stimuli that were either (a) more intense or (b) of lower frequency.

The ineffective regulation of N1 is consistent with theories of autism or RDLD related to the ineffective regulation of sensory input (Ornitz, 1989, review article). Because the auditory N1 and P2 are believed to be generated in primary and secondary auditory cortex, it is possible that the

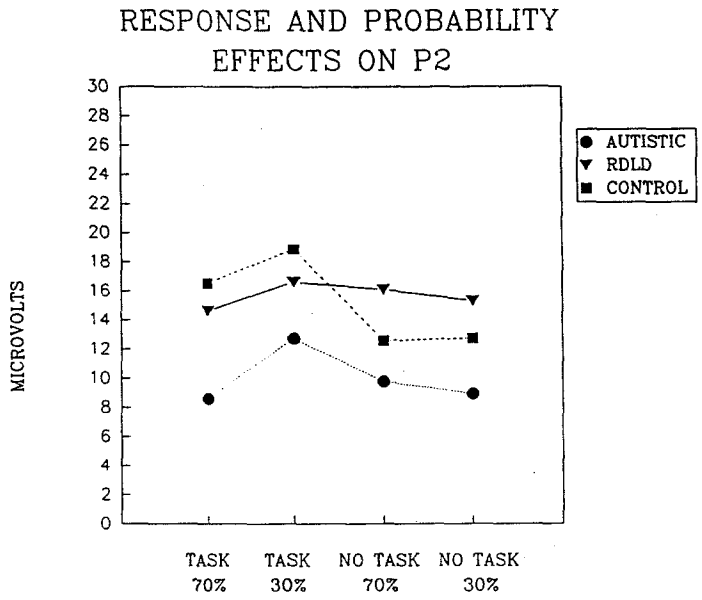

Fig. 4. The amplitude of P2 as it varies under conditions of task demand (Task = button press to high frequency and low frequency tone (either 1000 Hz or 2000 Hz), No Task = listen only to high frequency and low frequency tone) and stimulus probability $p = .70$ or $p = .30$.

ineffective regulation of N1 in both of the clinical groups of children are due to abnormalities in the physiology of these areas of cortex. This lends further support for abnormal serotonergic regulation in some children with autism, and provides the first suggestion of potential abnormal serotonergic regulation in children with RDLD. It is of course possible that the narrow range of stimuli sampled in the present study were insufficient to capture more specific, stimulus-dependent abnormalities of sensory N1 and P2 components of the ERP. Although, in evaluating a larger range of stimulus intensities, Bruneau et al. (1987) found no differences between autistic individuals and controls in N1 or P2 amplitudes, they did find greater variability of N1 in individuals with autism.

We also found that the N1 amplitude was more dependent on whether or not the task required a response, and was less dependent on the probability of specific stimuli for subjects with autism. Experiment 1 of the present study equates stimulus probability for the four different stimuli ($p = .25$ for each stimulus) and requires no task, thus differences between the autistic and RDLD children compared to the control group of

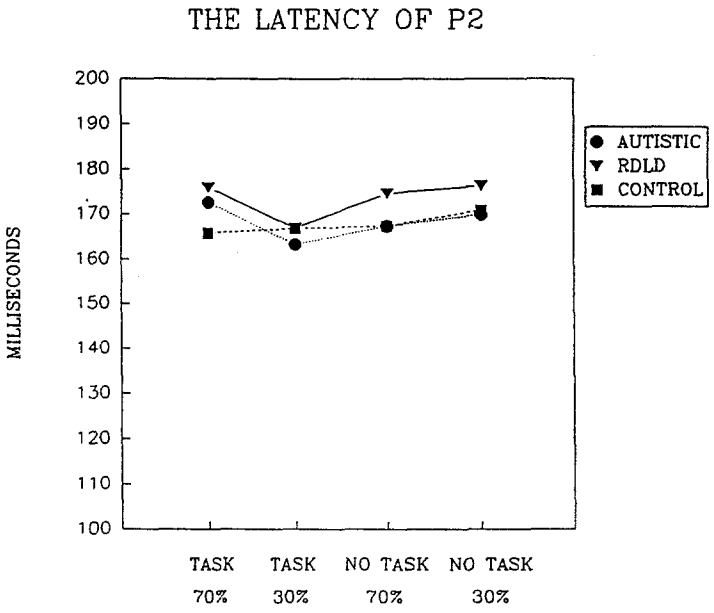

Fig. 5. The latency of N2 as it varies under conditions of task demand (Task = button press to high frequency and low frequency tone (either 1000 Hz or 2000 Hz), No Task = listen only to high frequency and low frequency tone) and stimulus probability $p = .70$ or $p = .30$.

children cannot be attributed to either probability or task effects. Other studies which have reported differences in N1 or P2 peak amplitudes have confounded manipulations of frequency or intensity with stimulus probability and task. N1 amplitudes of autistic subjects were found to be larger than N1 amplitudes of normal controls to rare stimuli in odd-ball target-detection tasks (Oades et al., 1987). However, in Experiment 2 we found autistic children to have essentially similar N1 amplitudes to both rare target and frequent auditory target stimuli. This finding is congruent with the report of the P3 in children with autism as also being less dependent on stimulus probability and more dependent on the presence or absence of a task (Lincoln et al., 1993).

RDLD children, however, demonstrated larger N1 amplitudes than normal control children, and tended to demonstrate larger N1 amplitudes than children with autism. Furthermore, RDLD children differed in the latency of N1. It is possible that the N1 is indexing some

aspect of the auditory processing deficit associated with RDLD. This task was clearly more difficult for the RDLD children than either of the other two groups of children evaluated. Perhaps, the children with RDLD devoted greater attention resource in order to discriminate the two tones. RDLD children have been found to have difficulty processing rapid acoustic information (Tallal et al., 1973a, 1973b, 1981). The 50-msec duration of the stimuli employed in the present experiments may have been too rapid to allow full processing without RDLD children having to simultaneously devote additional attentional resources as indexed by the increased N1 amplitude.

Lincoln et al. (1992) also suggested that the more basic problem in children with RDLD was related to the encoding of auditory information in short-term memory. At least three of the RDLD children had difficulty remembering which was the high or low tone in the Task condition of Experiment 2. The 2-second delay between stimuli appeared for some of the RDLD children to be too long to maintain the internal reference of whether the tone was high or low. Thus when they would hear the next tone, they had forgotten whether it was to be classified as high or low. This is why the response accuracy was so low for the RDLD children. Again, it is possible their larger N1 in this condition was indexing the additional attentional resources they needed to employ to perform the task.

If there is a problem in autism associated with sensory perception, it is unlikely to be attributed to abnormalities associated with intensity or frequency changes upon which changes of the P2 are dependent. Although P2 has been reported to be smaller in autistic compared to control subjects by Novick et al. (1980) and tended to be smaller in our autistic children compared to the normal controls, this difference was not statistically significant.

In Experiment 1 there were no specific controls for attention. However, all children wore headphones, and thus, were equally exposed to the sounds. It is difficult to imagine that differences across the three groups of children in their attention to the tones could have resulted in the three groups having essentially similar findings with respect to N1 and P2 amplitudes and latencies. However, both of these ERP components are affected by attention, and thus, may demonstrate differential sensitivity on ERP tasks when attention is directed or required. This was directly examined in Experiment 2. Assessing the possible interaction between attention, stimulus frequency, and stimulus intensity in children with autism and RDLD is appropriate for future study.

Conclusions

The N1 of children with either autism or RDLD, unlike control children, did not increase with increasing stimulus intensity. All three groups of children demonstrated essentially similar variation of P2 amplitudes and latency with changes in auditory intensity and frequency. These results provide partial support for the idea that some autistic children and RDLD children are not fully processing the intensity of auditory sensory information. This may be due to abnormalities associated with primary and secondary auditory cortex as well as potential abnormalities in serotonergic regulation upon which N1 appears to be dependent.

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