DOCUMENT RESUME

ED 358 947 PS 021 471

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TITLE Brain Electrical Activity Changes and Cognitive Development.
PUB DATE Mar 93
NOTE 6p.; Paper presented at the Biennial Meeting of the Society for Research in Child Development (60th, New Orleans, LA, March 25-28, 1993).
PUB TYPE Speeches/Conference Papers (150) -- Reports - Research/Technical (143)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Age Differences; Child Development; *Cognitive Development; *Males; *Physical Development; *Preadolescents; Visual Stimuli
IDENTIFIERS Brain Activity; *Cortical Electrical Activity; *Event Related Potentials

ABSTRACT

This study investigated the relationship of cognitive developmental changes to physiological and anatomical changes by measuring both types of data within the same subjects. Cortical electrical activity was measured in 24 males between 10 and 12 years of age. Event-related potentials (ERPs) were recorded from midline scalp electrodes during a visual task in which two different stimuli were presented sequentially. Half of the subjects in each age group were at Level 6 of Fischer's skill hierarchy; the other half were at Level 7. Advancement from Level 6 to 7 involves the acquisition of the ability to derive a single abstract concept from the comparison of two concrete instances of that concept. IQ was also measured for each subject. Results showed that the amplitude of P300 was significantly greater for boys in Level 7 compared to Level 6. P300 latency changed significantly as a function of age, but the change was not linear. Trial-to-trial variability of the ERP decreased from Level 6 to Level 7; however, this effect was only marginally significant. In general, results showed clear evidence that the physiological measures of P300 amplitude, P300 latency, and trial-to-trial variability correspond to developmental changes. (Author/MM)

# Brain Electrical Activity Changes and Cognitive Development

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Poster presented to the Society for Research in Child Development,
New Orleans, March 1993



## Abstract

The purpose of the present study was to investigate the relationship of cognitive developmental changes to physiological/anatomical changes by measuring both types of data within the same sample of subjects. Thus, we measured evoked cortical electrical activity in 24 males, eight each at the ages of 10, 11, and 12 years of age. Half of the subjects in each age group were assessed as being at Level 6 and half at Level 7 of Fischer's (1980) skill hierarchy. Advancement from Level 6 to 7 involves the acquisition of the ability to derive a single abstract concept from the comparison of two concrete instances of that concept. Event-related potentials (ERPs) were recorded from midline scalp electrodes during a visual "oddball" task in which two different stimuli were presented sequentially with respective probabilities of .2 and .8. IQ was also measured for each subject. Results showed that the amplitude of P300 was significantly greater for boys in Level 7 compared to Level 6 ($p < .05$). P300 latency was found to change significantly as a function of age, but the change was not linear. Trial-to-trial variability of the ERP was found to decrease from Level 6 to 7. This effect was only of marginal significance ($p = .056$), however.

Although developmental psychologists generally accept that cognitive changes are related to physiological and/or anatomical changes, rarely are both types of data gathered from the same sample of subjects. The purpose of the present study was to attempt to achieve this goal. Cognitive changes were manipulated by establishing six groups of preadolescent boys, two groups of 10-year-olds, two groups of 11-year-olds, and two groups of 12-year-olds. At each age, one group was assessed to be in Fischer's (1980) Level 6 (corresponding roughly to the late concrete operational stage), and one in Level 7 (corresponding to early formal operations). Thus, age and cognitive level served as the independent variables.

Dependent variables were electrophysiological, namely event-related potentials (ERPs) recorded during a visual "oddball" task in which two different stimuli (an "I" and an "F") were presented with unequal probabilities (.2 and .8, respectively). The subject had to manually respond to the rare stimulus (i.e., to the "I"). The following measures were derived from the ERPs recorded to the rare stimulus:

1. P300 amplitude and latency. P300 is elicited by decision-making processes such as those in the oddball task. This ERP wave represents activity from several generators within the brain, most likely parietal and frontal cortical regions as well as the hippocampus (Vaughan & Arezzo, 1988). It was predicted that P300 amplitude would increase and latency would decrease from Level 6 to 7.

2. Cortical coupling measures the degree to which ERPs from any two electrodes show correlated activity. This measure was used as an estimate of the degree to which different areas of the brain were functioning synchronously. It was predicted that coupling would increase from Level 6 to 7.

3. Trial-to-trial variability. These measures included the amplitude variability of each digitized point of the ERP, and the latency variability of the P300 peak. These measures were used as estimates of the consistency of the brain's response to the stimuli from trial to trial. It was predicted that both types of variability would decrease from Level 6 to 7.

Verbal IQ was also measured for each subject. This was done in order to help discern the extent to which physiological differences measured between cognitive levels were actually attributable to differences in cognitive development as opposed to differences in intelligence.

## Method

### Subjects

The final sample consisted of 36 preadolescent males. Twelve were 10 years of age, 12 were 11 years, and 12 were 12 years.

### Design

This study utilized a quasi-experimental design with the independent variables being age and cognitive level, and the dependent variables being various ERP measures. Cognitive level was measured by a 2-step procedure outlined below. At each age, half of the subjects were determined to be in Level 6 and half in Level 7.

### Procedure

Subjects were first determined to be in either Level 6 or Level 7 of Fischer's (1980) skill hierarchy. Assignment into levels was based upon performance on Fischer's Single Abstraction Arithmetic Test. Advancement from Level 6 to 7 involves the acquisition of the ability to derive a single abstract arithmetic concept, such as addition, from the comparison of two concrete instances of that concept. Cognitive level was validated by administering Piaget's Colored Token Test (Inhelder & Piaget, 1958) in which subjects are asked to form all possible pairs from six groups of different color tokens. Subjects had to pass both the Single Abstraction Arithmetic Test and the Colored Token Test to be considered functioning at Level 7; subjects who failed both tasks were identified as operating within Level 6.

Subjects were also assessed for verbal IQ using the Slosson Intelligence Test-Revised. Correlations of this test with the full scale of the Wechsler Intelligence Scale for Children-Revised and the Wechsler Intelligence Scale for Adults-Revised are in the .80s.

ERPs were recorded from four midline electrodes placed over occipital (Oz), parietal (Pz), central (Cz), and frontal (Fz) cortical regions. Eye movement (EOG) artifact was monitored by two additional electrodes. Stimuli for ERP recording consisted of single letters presented for 80 ms on a computer screen. The letter "F" was designated the standard and presented on 80% of the trials; the letter "I" was the target and presented on 20% of the trials. The subject was instructed to respond to each target with a button press. For each stimulus, EEG data were stored on computer disk 100 ms prior to the onset of the stimulus and for 1200 ms after stimulus onset. A minimum of 200 trials were presented (40 target, 160 standard). Trials containing EOG artifact were automatically rejected online and replaced.

Four average ERPs were calculated for each subject, one from each electrode site, from the 40 single-trial waveforms recorded to the targets. P300 amplitude and latency, cortical coupling, and trial-to-trial variability were then derived from each subject's raw data.

## Results

The data were analyzed using a multivariate analysis of variance (MANOVA) with age, cognitive level, and electrode site as independent variables. All MANOVA Fs that were significant at the .05 level were then examined with a Tukey's post-hoc test. Significant findings were also analyzed using a multivariate analysis of covariance (MANCOVA) with IQ as the covariate.

Each measure except cortical coupling showed notable developmental outcomes. For P300 amplitude, there was a significant interaction between cognitive level and electrode site ($F(2,29) = 4.06$, $p < .05$). Tukey's test revealed that P300 amplitude increased from Level 6 to Level 7 at the Cz electrode (see Figure 1). When the influence of IQ was statistically removed from the analysis in the MANCOVA, the significance of the level X electrode interaction was attenuated ($F(2,29) = 3.03$, $p = .06$). Thus, cognitive level differences are manifest in this electrophysiological measure, but there is also some confounding by IQ. Two other analyses confirm this. As seen in Table 1, Level 7 boys had higher IQs at each of the three ages. Furthermore, IQ and P300 amplitude showed a significant positive correlation at Cz ($r = .60$, $p < .05$).

P300 latency showed no effects for cognitive level, but there was a main effect for age ($F(2,29) = 4.11$, $p < .05$). This effect was not linear, as can be seen in Figure 2. This outcome was unchanged when the influence of IQ was removed in the MANCOVA.

Although latency variability showed no significant effects, a marginally significant main effect for cognitive level was found for amplitude variability. As was predicted, amplitude variability decreased from Level 6 to 7 ($F(1,30) = 3.86$, $p = .056$). This effect remained essentially unchanged in the MANCOVA results ($F(1,30) = 3.69$, $p = .06$).

## Discussion

This study found clear evidence that the physiological measures of P300 amplitude, P300 latency, and trial-to-trial variability correspond to developmental changes. However, this research at best can only suggest that the ERP differences observed between Levels 6 and 7 of Fischer's hierarchy are actually related to cognitive developmental changes. A strong conclusion of this sort is precluded for two reasons. First, it was found that P300 amplitude varied not only with cognitive level but also with IQ. Thus it is not clear whether the P300 amplitude increase represents development from Level 6 to 7, or the more general difference in intelligence between the groups at each level. Longitudinal studies which measure cognitive developmental change within the same subjects must be done to address this issue.

Second, P300 represents a decision process on the part of the subject. Therefore, it must be asked whether P300 differences are due to brain differences between Level 6 and Level 7 subjects, or problem-solving strategy differences between Level 6 and Level 7 subjects. Nevertheless, these results suggest that a cognitive developmental neuroscience is feasible by the use of well-established techniques from the two domains.

## References


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Table 1

Mean verbal IQ for each cognitive level at each age

| Cognitive Level | Age | | |
|---|---|---|---|
| | 10 | 11 | 12 |
| 6 | 89.1 | 91.1 | 85.8 |
| 7 | 101.1 | 103.5 | 101.8 |

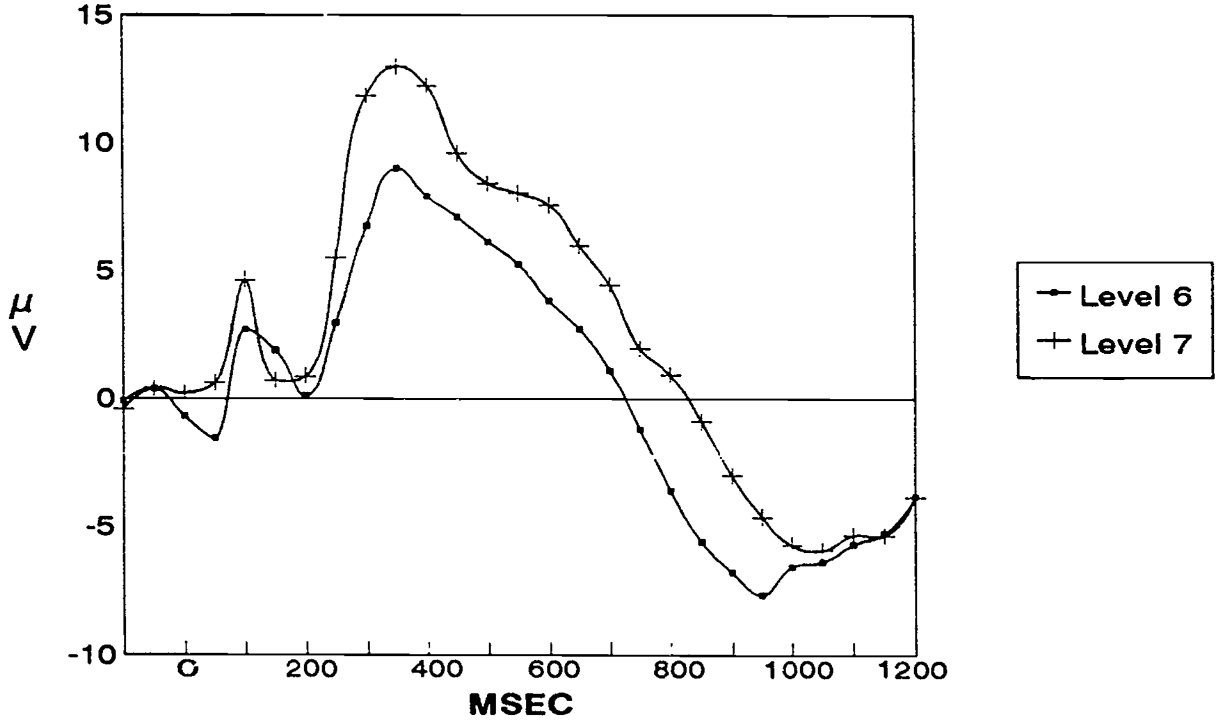


Figure 1. Grand average ERPs for P300 amplitude at the CZ electrode for Level 6 and Level 7 subjects.

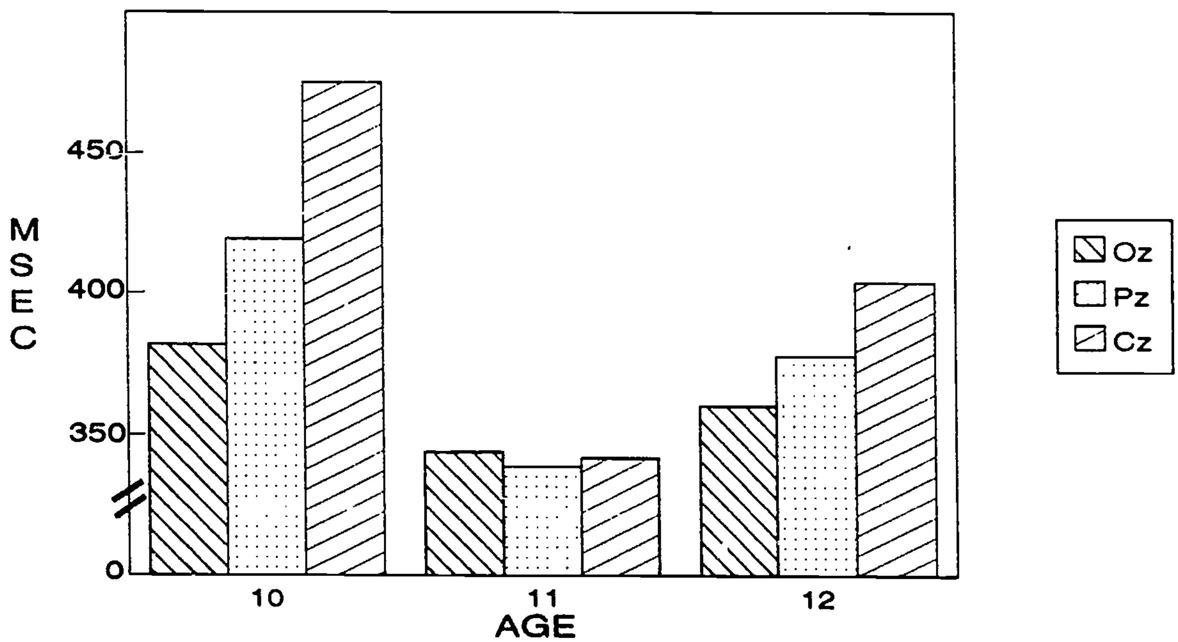


Figure 2. Mean P300 latencies for the 3 age groups for each electrode.