

# DEVELOPMENT OF ERROR MONITORING ERPs IN ADOLESCENTS

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## Introduction

In a target discrimination task, trials with incorrect responses elicit event-related potentials (ERPs) that include two components, an error-related negativity (ERN) and a later error-positivity (Pe). Substantial evidence points to the anterior cingulate cortex (ACC) as the source generator of the ERN<sup>1,2</sup> and it is modeled to be dopaminergically driven.<sup>3</sup> The ACC is involved in executive functions with major connections between the prefrontal cortex (PFC) and limbic system.<sup>4</sup> Given the continued maturation of the ACC, PFC, and dopamine systems into young adulthood, our aim was to investigate the development of ERPs to correct and incorrect (error) responses.

## Method

### Participants:

- 124 children aged 7 to 18 years (see Table 1)
- 22 adults 19-25 years

### Procedure:

- 480-trial 5-letter arrays visual flanker task
- Stimuli: 160 congruent (HHHHH, SSSSS) and 320 incongruent (HHSHH, SSHSS)
- Stimulus duration: 250 ms
- ISI: 1 s (age 10 to adult) 1.5 s (age 7-9)

### Electrophysiological Measurements:

- 29 scalp sites, 2 bipolar eye monitors
- Fz, FCz, Cz, Pz scored (some Ss missed FCz so we are omitting analyses at this site here)
- EOG artifact rejection ( $\pm 100 \mu V$ )
- referenced offline to averaged ear
- recorded at 500 samples/s
- .23 to 30 hz band pass

Table 1 – Number of Participants

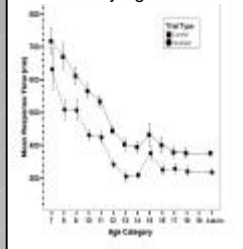
| Age          | Gender    |           | Total      |
|--------------|-----------|-----------|------------|
|              | Females   | Males     |            |
| 7            | 4         | 8         | 12         |
| 8            | 8         | 2         | 10         |
| 9            | 12        | 6         | 18         |
| 10           | 4         | 6         | 10         |
| 11           | 7         | 4         | 11         |
| 12           | 8         | 10        | 18         |
| 13           | 5         | 3         | 8          |
| 14           | 6         | 3         | 9          |
| 15           | 5         | 3         | 8          |
| 16           | 4         | 2         | 6          |
| 17           | 3         | 3         | 6          |
| 18           | 5         | 3         | 8          |
| young adults | 18        | 9         | 27         |
| <b>Total</b> | <b>89</b> | <b>62</b> | <b>151</b> |

## Results

### Behavioral Data

Reaction times (see Figure 1): RT correlated with age in correct trials ( $r = -.75, p < .0005$ ) and incorrect trials ( $r = -.61, p < .0005$ ). Repeated measures ANOVA showed incorrect responses were significantly faster than correct responses ( $F_{1,89} = 152.8, p < .0005$ ), a significant difference in age group ( $F_{10,89} = 20.4, p < .0005$ ) and an interaction between RT of response type and age groups ( $F_{10,89} = 2.91, p = .003$ ).

Figure 1 - Reaction time by age



Error rates ranged from 2.5% to 29.3% across subjects ( $M = 11.05\%$ ). Age significantly correlated with error rate,  $r = -.32, p < .0005$ , with children generally having a larger error rate than adults.

### Electrophysiological Data

The adult ERN and Pe were similar to those in previous studies (See Figure 2). The ERN shows an increase in amplitude with age over the 7 to 18 years age span,  $R^2 = .146, F_{1,122} = 20.9, p < .001$ . The Pe amplitude did not change with age,  $r = -.08, n.s.$  See Figure 3.

Figure 2 - Averages for adults

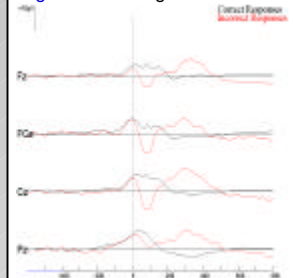
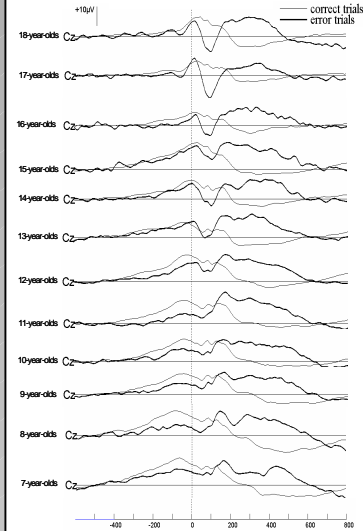


Figure 3 - Average waveform at Cz for each age group



The ERN waveforms are much more variable in children than adults (see figures 4-6)

Figure 4 - Selected waveforms from individual adults (age 19-25) at Cz. Almost all adults had a strong ERN and Pe, one of the smallest shown last in this figure.

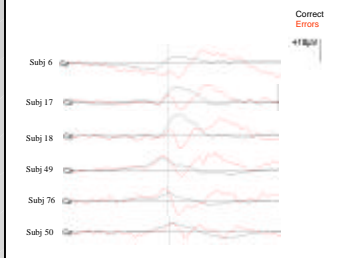


Figure 5 - Selected waveforms from individual adolescents (ages 13-17) at Cz. Adolescents sometimes exhibit an ERN, and always a Pe.

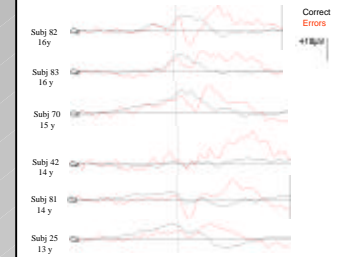
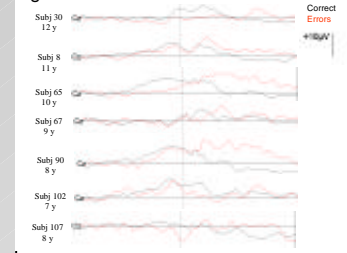


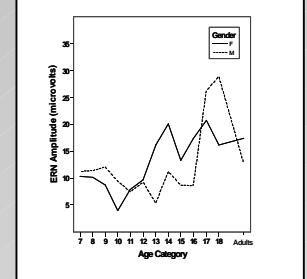
Figure 6 - Selected waveforms from individual children (ages 7-12) at Cz. Younger children hardly ever exhibit a strong ERN, but always exhibit a Pe. A rare strong ERN is shown last in this figure.



### Nonlinear Effects Across Adolescence.

The linear and quadratic age effects in the peak-to-peak ERN accounted for 20.4% and 9.5% of the variance in the ERN, respectively,  $F_{1,122} = 31.2, p < .001$  and  $F_{1,121} = 16.4, p < .001$  (see Figure 7). The ERN quadratic distribution indicated an initial drop in amplitude with a subsequent rise through adolescence. The girls have a minimum value at age 10 years while for the boys the lowest value is at age 13 years.

Figure 7 - Age x Gender interaction in ERN amplitude measured peak-to-peak (P3-to-ERN) in  $\mu V$ .



## Conclusions

- 1) Older children sometimes show an ERN and most always a Pe.
- 2) Younger children hardly ever show a strong ERN but most always a Pe.
- 3) Children know that they are making errors but children have different ERPs to error responses. Further analyses are needed to determine possible differences in the nature of error monitoring reflected in the ERPs.
- 4) The data presented here support a continued physiological maturation of the ACC and its connections with the PFC through adolescence given that the ERN is generated in the ACC and develops into adolescence, not reaching adult levels until late teen years. This contrasts with the development of the Pe component, found to be very robust even in the young children.

## References

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