Relationship of Error-related Negativity to Cognitive Skills From 7 to 18 Years

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Introduction

- The error-related negativity (ERN) is a component of the ERP that is associated with acknowledged incorrect responses that occur in target discrimination tasks[1,2] and is associated with the anterior cingulate cortex (ACC).[3,4]
- Recent evidence indicates that the ERN amplitude in error trials increases with age, qualified by a nonlinear change.[5]
- Figure 1 illustrates an age by gender interaction of the ERN amplitude, with females showing an initial drop in amplitude and a subsequent rise through adolescence, while for males the lowest value is at age 13.[5] In contrast to the ERN, the Pe amplitude did not change with age.[5]
- Essential to understanding the developmental pattern of the ERN is the exploration of the question of why some young children produce strong ERNs while most do not. Further studies are needed to determine the extent to which executive functions and personality influence the production of ERNs.

Purpose

- To examine whether cognitive or executive functions accounts for some of the individual differences of the ERN seen in children.
- To explore whether performance on cognitive tasks explain some of age and gender interaction in the maturation of the ERN.

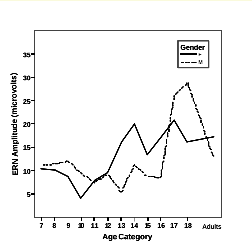


Figure 1. Age x Gender interaction in ERN amplitude measured peak-to-peak (P3-to-ERN) in µV. Linear and quadratic age effects in the ERN accounted for 20.4% and 9.5% of the variance in the ERN, respectfully, $F(1,122) = 31.2$, $p < .001$ and $F(1,121) = 16.4$, $p < .001$. Baseline-to-ERN produced the same results.

Method

Participants

- 121 youth, ages 7 to 18 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
- ERN scored at Cz (some Ss missed FCz)
- EOG artifact rejection (+/- 100 µV)
- re-referenced offline to averaged ears
- recorded at 500 samples/s
- .23 to 30 Hz band pass

Cognitive Behavioral Measurements

- Estimated IQ (WASI)
- Working memory
  - 1-back
  - 2-back
- Stroop
- Embedded figures
- Selective Letter Cancellation
- Motor speed (Crossing Off A's task)
- Mazes
- Digit Span Forward
- Digit Span Backward
- Word Recall
- Number cancellation
  - 1 number
  - 3 numbers
- Line Orientation

Results

Correlations Between Age and Cognitive Performance

- 15 of 18 measures had significant linear relations (see Table 1).
- Plus 8 had quadratic functions with age (see Figures 2 and 3 for examples).

Table 1

Behavioral Tests	Age *r*	ERN *r*
Estimated IQ		
Total IQ (T-scores)	NS	NS
IQ Vocabulary (raw scores)	.85****	-.30***
IQ Matrix Reasoning (raw scores)	.63****	-.19*
Behavioral Tasks		
Working Memory		
2-back	.62****	-.26**
Dual Task	.59****	-.27**
Stroop Color Words	.74****	-.30***
Mazes	.52****	-.24**
Digit Span Backward	.57****	-.18*
Digit Span Forward	.54****	NS
Motor Speed (Cross off A's)	.77****	NS
Search (Selective Letter Cancellation)	.71****	-.22*
Word Recall	.41****	NS
Number Comparison		
1 Number (total)	NS	NS
1 Number (time)	-.68****	NS
3 Number (to tal)	NS	NS
3 Number (time)	-.68****	NS
Line Orientation	.58****	-.20*
Embedded Figures	.57****	NS

Key: * < .05; ** <.01; ***<.001; ****<.0005

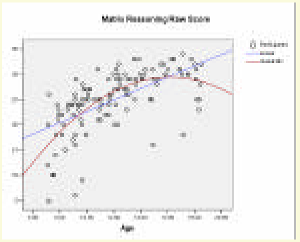
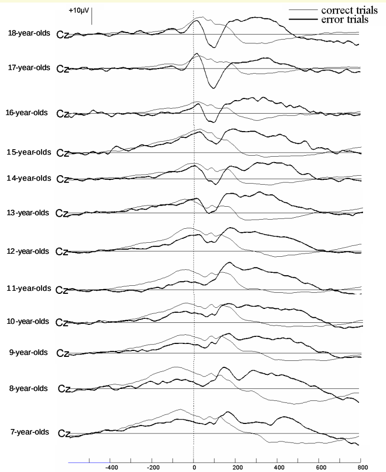


Figure 2. Linear regression for matrix reasoning raw score was $F(1,118) = 42.62$, $p < .0005$, adj. $r2 = .259$ and for quadratic regression $F(2,117) = 27.17$, $p < .0005$, adj. $r2 = .306$.

Correlations Between Age and ERN Amplitude

- Pearson r correlations were conducted for age and ERN amplitude at Cz, $r = .381$, $p < .0005$. Figure 4 demonstrates the increase in ERN amplitude with age, modified by a quadratic relationship (see Figure 1).

Figure 4. ERP Grand Averages for each age group at Cz.



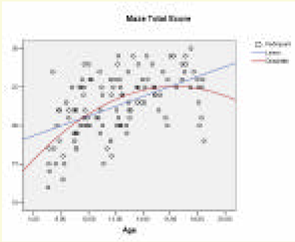


Figure 3. Linear regression for mazes total score was $F(1,117) = 75.65$, $p < .0005$, adj. $r2 = .387$ and for the quadratic regression $F(2,116) = 52.20$, $p < .0005$, adj. $r2 = .465$.

Correlations Between ERN amplitude and Cognitive Performance

- 9 of 18 measures had significant linear relations (see Table 1).
- Regression analysis performed to determine if cognitive performance accounts for ERN beyond the age-related variance:
  - Only 2 tasks remain (motor speed and 1 number comparison time).
  - When quadratic (age^2) is included, the motor speed tasks no longer account for ERN variance.
- Gender interaction effects - males and females (8 to 17 years) examined separately:
  - Females: no cognitive variance in ERN once age and age^2 are removed.
  - Males: performance on 3 of the cognitive measures account for significant variance after removing age and age^2 (see Table 2).

Table 2

Cognitive Measure	Change Statistics: R Square	F	Sig. F
IQ vocabulary raw	.064	4.261 (1,44)	.045
IQ matrix reasoning raw	.109	7.567 (1,43)	.009
Mazes	.094	6.494 (1,44)	.014

Conclusions

- There are linear and quadratic effects of Age with a gender interaction on cognitive performance and ERN amplitude.
- The ERN and performance on cognitive tasks are closely tied to the linear and nonlinear growth patterns. Consequently age accounts for much of the variance in the ERN, especially when considering males and females together.
- The gender differences in ERN maturation pattern may be explained by general intelligence levels in males only. Thus, for males, but not females, error monitoring may be influenced by individual differences in intelligence.

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