Brain and Behavioral Correlates of Error Monitoring in Young Children

Keye Xu[1], William J. Gehring[2], Matthew H. Kim[3], Frederick J. Morrison[2] & Jennie K. Grammer[1]

University of California, Los Angeles[1], University of Michigan, Ann Arbor[2], Educational Policy Improvement Center[3]

B.E.A.R Lab

Introduction

- Children's error monitoring is a key aspect of their Cognitive Control abilities (e.g., working memory, attention shifting).
- The ability to learn from errors and appropriately adjust later behaviors is important for academic and social learning.

Behavioral Measures of Error Monitoring

- **Post-Error Slowing (PES) :** Participants tend to have longer reaction times (RT) for trials immediately following errors than for trials following correct responses.
  - Debate on mechanism and adaptive meaning of PES.
  - Less is known about development and functions of PES.
- **Post-Error Improvement in Accuracy (PIA):** Accuracy tends to increase following error commission.
  - Thought to reflect trial-to-trial adjustment after errors.
  - A sign of attentional top-down control.

ERP Measures of Error Monitoring

- **Error-Related Negativity (ERN):** Thought to indicate automatic error detection and conflict resolution processes during response monitoring.
- **Error Positivity (Pe):** Considered to reflect the conscious awareness of and increased attention to errors.

Research Questions

The purpose of this study is to investigate post-error adjustment in children from 4 to 8 years old, using both behavioral and electrophysiological data from a Go/No-Go Task.

RQ1: Do behavioral measures of error monitoring (PES/PIA) change as a function of age in children from 4 to 8 years old?

RQ2: In a speeded discrimination task, do behavioral measures of error monitoring (PES/PIA) predict children's overall change in task performance?

RQ3: Does error-related brain activity (ERN and Pe) relate to behavioral measures of error monitoring (PES and/or PIA) in children from 4 to 8 years old?

Method

- **Sample:** 312 children (M = 5.98, SD = 0.80, range = 4.01 – 8.22 years, 143 boys) from three complementary brain-behavior investigations.
  - Two school-based and one laboratory-based studies.
- **Procedure:** All children completed a child-friendly Go/No-Go task. During the task, EEG data were acquired using a BioSemi Active Two system with 32 Ag/AgCl electrode cap.

The Go/No Go Zoo Game

- **Behavioral Measures:**

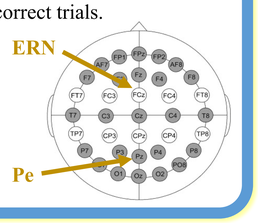
PES: Mean RT on correct trials following error – Mean RT on correct trials following correct response.

PIA: Accurate rate post-error trials – Accurate rate on post-correct trials.

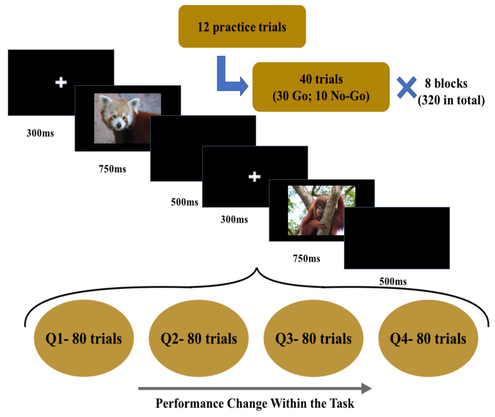
- **ERP Measures:**

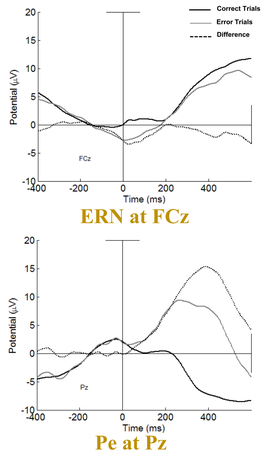
ERN/CRN: The mean amplitude calculated from a time-window of -50-50ms around the response.

Pe: The mean amplitude calculated from a time window of 200-500ms after the response.



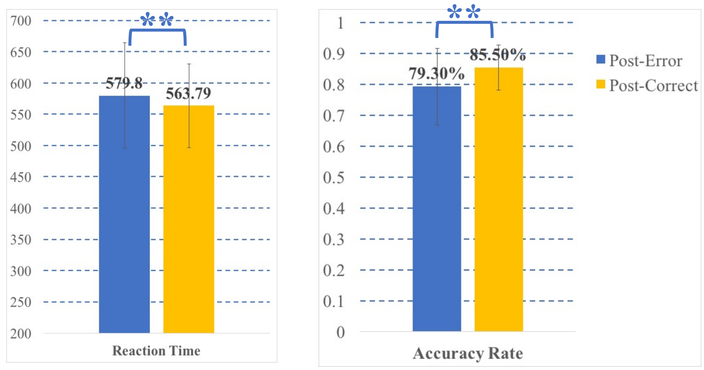
Zoo Game





Results

Figure.1 Mean Reaction Time and Accuracy Rate after Error VS. Correct Trials



- The mean RT after errors was significantly slower than the mean RT after correct responses, t (311) = 5.61, p < 0.01.
- Children were significantly less accurate after committing an error, compared to after a correct response, t (311) = -11.58, p < 0.01.

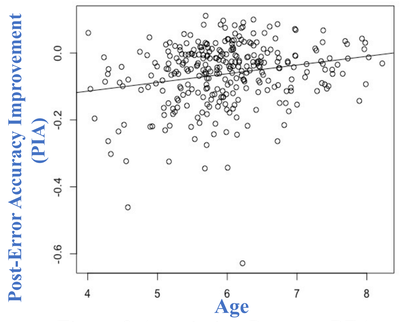


Figure.2 Association Between PEA and age

RQ1: Do PES/PIA change as a function of age in children from 4 to 8 years old?

- No correlation was found between the magnitude of PES and children's age.
- However, age was significantly correlated with the magnitude of PIA, with older children showing smaller accuracy impairment, r (303) = 0.218, p < 0.01.

Results

RQ2: Do PES/PIA predict children's in task performance change?

- **Multilevel Growth Model** allows us to examine the individual differences in children's changing performance in the task. Performance change was modeled as the accuracy change within task across each quarter.

  - Level-1 Within Subject Model

$$Y_{ij} = \beta_{0j}^{*} + \beta_{1j}^{*} T_{ij} + R_{ij} \qquad R_{ij} \sim N(0, \sigma^2)$$

Y_{ij}: Accurate rate for children j at time-point i;
T_{ij}: Time-point indicator taking values 0, 1, 2, 3
β_{0j}: The initial accuracy rate for children j.
β_{1j}: Averaged performance change for children j in Zoo Game

  - Level-2 **Model 1** – *Does PES influence children's performance change?*

$$\beta_{0j} = \gamma_{00} + \gamma_{01}^{*}PES + U_{0j}; \quad \beta_{1j} = \gamma_{10} + \gamma_{11}^{*}PES + U_{1j}$$

  - Level-2 **Model 2** – *Does PIA influence children's performance change?*

$$\beta_{0j} = \gamma_{00} + \gamma_{01}^{*}PIA + U_{0j}; \quad \beta_{1j} = \gamma_{10} + \gamma_{11}^{*}PIA + U_{1j}$$

- Though all children made more errors at the end of the task than the beginning, those who had larger PES and PIA scores showed slower performance decline.
  - Regression coefficients were significant for both models;
  - Model 2 – with PIA – fit the data slightly better.

RQ3: Does error-related ERPs relate to PES and/or PIA?

- Neither PES nor PIA were significantly correlated with children's ERN/CRN amplitude during the Zoo Game.
- Only PIA was correlated with the correct Pe amplitude at a posterior site (Pz), r = -0.12, p = 0.04.

Discussion

- All children showed a significant slowing effect after making an error, though no age-related changes in slowing were observed.
- **Most children showed impaired accuracy on post-error trials compared to post-correct trials**, which is contrary to results from adult studies. However, older children had larger and more adult-like PIA, indicating the growing of inhibition ability at this age period.
- Both PES and PIA predicted a more adaptive changing of performance across the Zoo Game.
- These results provide insight into choosing the best indicators from responses inhibition tasks, regarding different task properties. In the current study, **PIA might be a better indicator of error monitoring and adjustment** due to the missing of RTs in Go/No-Go task.
- Results also indicate that **errors may be more like distractors** than chances of learning for young children at this age.
- More trial-to-trial analysis of ERP data is needed to further explore the relationship between PES/PIA and post-error ERP components.

This material is based upon work supported by National Institutes of Health grant R21 HD059085 and from the National Science Foundation NSF BCS 1356118.