Associations of Neural Correlates of Cognitive Control and Self-Reported Math Anxiety Level

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Introduction

Math anxiety (MA): An acute feeling of fear, tension, apprehension or worry about mathematics. Related but distinct from general anxiety.

- Impedes mathematic performance and influences STEM-related career choices.
- Might be related to a deficit in cognitive control.

Cognitive Control: Processes that support adaptive behavior in service of current goals.

- Electrophysiological methods offer another level of information to understand cognitive control.
- High math salience context might exaggerate the impairment of cognitive control among individuals with high MA.

Few studies have investigated the neural correlates of MA in relation to cognitive control as a way of understanding the underlying mechanisms of MA.

Neural Correlates of Cognitive Control:

- **Error-Related Negativity (ERN):** Thought to indicate automatic error detection (also degrees of saliency) and conflict monitoring processes;
- **P300:** Thought to indicate the degree of attentional allocation toward the presentation of stimuli.

Research Questions

RQ1: What is the relationship between neural correlates of cognitive control (ERN and P300) and self-reported MA rating?

RQ2: Does the correlation between neural correlates of cognitive control and MA vary by high vs. low in math salience?

Method

- **Sample:** 57 undergraduate students (M_{age} = 19.45, N_{men} = 26).
- **Procedure:**
  - Ps completed four computerized tasks (order counterbalanced) from which their electrophysiological activities were collected.
  - Ps also completed several questionnaires, including a self-reported math anxiety scale, a general anxiety scale and a behavioral attention control scale.
  - EEG data were acquired using a ActiChamp system with 32 Ag/AgCl electrode cap (actiCAP).
- **Survey Measures:**

Abbreviated Mathematics Anxiety Rating Scale (A-MARS): 25 items, 5-point Likert scale to indicate one's anxiety level, from "Not at all" to "Very much". E.g., "Getting ready to study for a math test".

State-Trait Anxiety Inventory (STAI): Self-reported of one's general anxiety level, 20 items for State and Trait anxiety each with 4-point Likert scale. E.g., "I feel nervous and restless".

Attentional Control Scale (ACS): 20 items on a 4-point Likert scale. E.g., "It's very hard for me to concentrate on a difficult task when there are noises around".

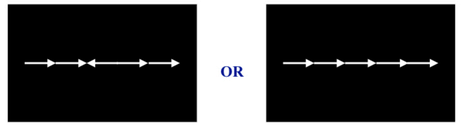
Computerized Tasks

- **Approximate Number Sense (ANS) Task – High Math Salience**

- 60 trials of Quantity Comparison
- 60 trials of Luminosity Comparison

Stimuli Present: 500ms

- **Flanker Task – Low Math Salience**



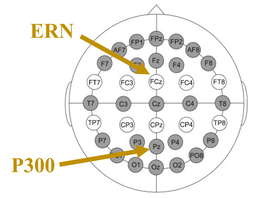
- 6 blocks of 384 trials in total;
- Congruent/incongruent trial ratio is 1:1.

250ms

- **ERP Measures:**

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

P300: The mean amplitude calculated from a time-window of 300-700ms after the presentation of the target stimulus.

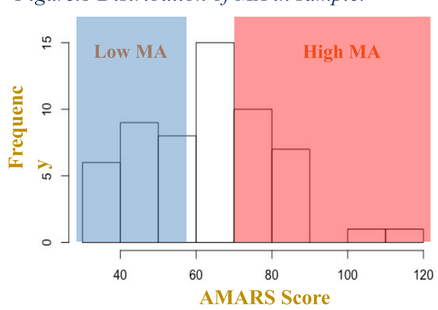


Results

Behavioral Results

- Participants' math anxiety level was significantly correlated with both state/trait anxiety level, r(56) = 0.33, p < .05; r(56) =0.30, p < .05.
- A trending gender effect was found: women reported a higher level of math anxiety, r(56) = 0.26, p = .053. Additionally, women showed a significantly worse accuracy rate during the ANS task, r(56) = -0.29, p<.05.
- Self-reported ACS score was significantly correlated with the trait/state anxiety level, r(56) = -0.34, p < .05; r(56) = -0.29, p < .05, such that ↑ general anxiety associated with ↓ attentional control abilities.
- Math anxiety showed a non-linear relationship with behavioral performance in Flanker task, but not with ANS.
  - ↑ AMARS score with ↑ task accuracy in Flanker among low MA group, r(18) = 0.58, p <.05; but ↑ AMARS score with ↓ task accuracy during Incongruent trials in Flaker among high MA group, r(16) = -0.45, p = .07.

Figure.1 Distribution of MA in sample.

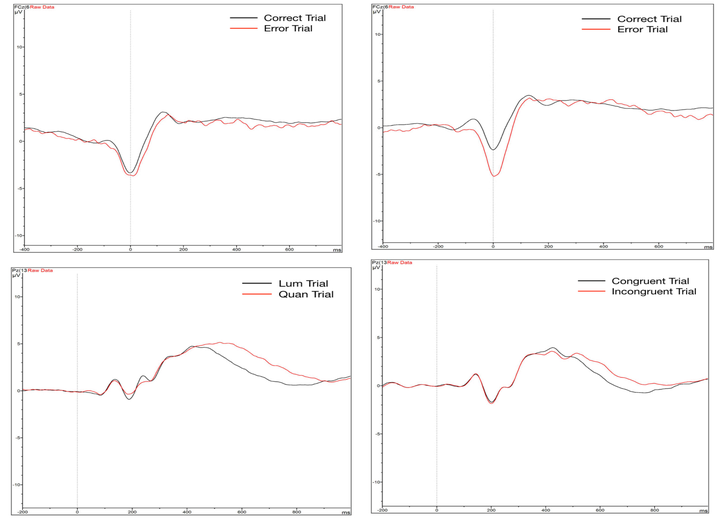


ERP Results

- ERN was detected in both ANS and Flanker tasks, F(1, 52) = 12.56, p < .01 (ANS); F(1, 47) = 35.73, p < .01 (Flanker), see Figure 2.
- Larger P300 was found towards a Quantity vs. Luminosity stimulus, F (1, 52) = 7.57, p < .05; and larger P300 for a Incongruent vs. Congruent stimulus in Flanker, F (1, 47) = 5.04, p < .05, which are signs of increased attention allocation, see Figure 2.
- No association identified between ERN/P300 and behavioral performance in both tasks.

Results

*Figure.2 **First row: ERNs at FCz; Second row: P300s at Pz.** Left are from the ANS task and right are from the Flanker task.*



- Women showed a more positive amplitude of P300 in both conditions in ANS task, r(53) = 0.28/0.34, p < .05, as well as in the Incongruent condition in Flanker task, r(48) = 0.29, p< .05.

MA levels and Neural Components

- People's MA level was not significantly correlated with the ERN/CRN amplitude nor the P300 amplitude in both ANS and Flanker task.
  - However, higher MA level was marginally correlated with a larger difference between ERN and CRN amplitudes during the Flanker task, among male participants only, r (22) = -0.38, p = .08.
  - AMARS score was associated with an greater amplitude difference between luminosity and quantity trials, r(17) = -0.50, p < .05, in low MA group only.

Discussion

- This is the **first study to our knowledge showing evidence suggesting an ERN occurs following error commission during the ANS task**.
- Overall, women **reported higher MA levels** , showed **impaired behavioral performance,** and payed **more attention to stimuli on a high math-salient task**. However, no gender difference was found with error- related ERPs during both tasks.
- **Only men with higher MA levels showed an enhanced error detection** during the Flanker task.
- **Gender stereotype about women and their math abilities** might influence the way women and men interpret their negative emotions towards math, which could be one possible explanation of the gender difference in the current study.
- **Moderate levels of MA** actually result in **better attentional control and performance** during cognitive tasks. It also would be interesting to further explore if this effect vary in different gender groups.
- **The limited number of participants with high MA level** might contribute to a lack of significant findings in the study. Future studies should purposefully recruit individuals with low vs. high MA to better investigate the difference.

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