Neural Mechanisms of Reward Processing in ASD

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BACKGROUND

INDIVIDUALS WITH AUTISM SPECTRUM DISORDER (ASD) show impairments in performance monitoring, a necessary part of feedback-based learning. Performance monitoring reflects on-going evaluation of the success or failure of an individual's actions. It occurs during feedback appraisal and reward processing and entails error detection to optimize future behavior. Difficulties with performance monitoring have been posited to contribute to deficits in ASD.

- Spatially, fMRI implicates anterior cingulate cortex (ACC) in performance monitoring
  - Integrating reward and punishment valences, magnitudes, and probabilities with adaptive behavior, especially self-monitoring
- Temporally, EEG reveals analogous and distinct stages of processing
  - Error-related negativity (ERN): ~50-100 ms after an error; reflects *self-perceived* inconsistency between intended and actual outcomes
  - Feedback-related negativity (FRN): ~250 ms in response to *external* feedback indicating outcome worse than expected
  - Error positivity (Pe): ~200-500 ms following ERN; related to error awareness and the adjustment of response strategies such as post-error slowing in reaction times

ACC FUNCTIONING IN CHILDREN WITH ASD and typically developing (TD) children has been investigated in three recent ERP studies.

- Groen *et al.* (2008): No difference in ERN or Pe during a feedback-learning task between children with ASD and TD children; however, ASD sample included subthreshold individuals
- Vlamings *et al.* (2008): Reduced ERN during an auditory decision task in children with ASD compared to TD children
- Larson *et al.* (2011): Comparable FRN evoked by wins versus losses in a guessing game among children with ASD and TD children

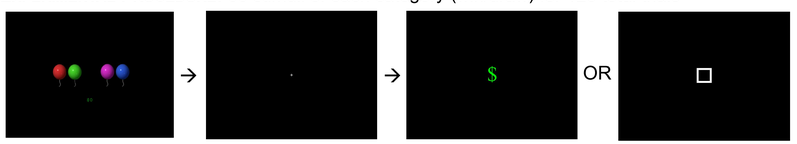
IN THIS STUDY we investigated the FRN as well as a novel component, the "feedback positivity" (Pf), during a simple reward task in children with ASD and TD children. We predicted that, because wins versus draws (rather than losses) more closely resembles the subtle distinctions of social feedback, children with ASD would display reduced FRN.

METHOD

Participants

GROUP	IQ	AGE	GENDER
ASD (n=22; based on ADOS and DSM-IV-TR clinical dx)	Mean: 105.1 Range: 79-133	Mean: 10.9 Range: 7.0-15.0	Female: 23% Male: 77%
TD (n=44; matched for Full Scale IQ and gender)	Mean: 106.6 Range: 86-139	Mean: 13.7 Range: 10.5-17.8	Female: 25% Male: 75%

Experimental Procedure: 60 stimuli of each category (win/draw) for 120 total trials



ERP Data Acquisition and Processing

- EGI 128 electrode Geodesic Hydrocel Net
- Four windows averaged over four electrodes
  - N1: 79-179 ms
  - P1: 151-251 ms
  - FRN: 231-371 ms
  - Pf: 301-401 ms (TD); 341-401 (ASD)

Statistical Analysis

- Repeated Measures ANOVA; age as a covariate
- 2 x 2 design
  - Group: ASD versus TD
  - Condition: win versus draw (no monetary gain or loss)

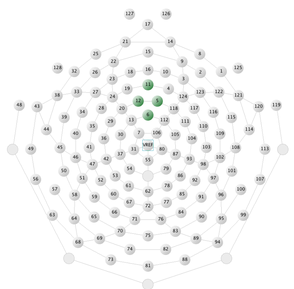


Figure 1: FRN montage. Data were averaged across 4 electrodes (5, 6, 11, 12) above ACC.

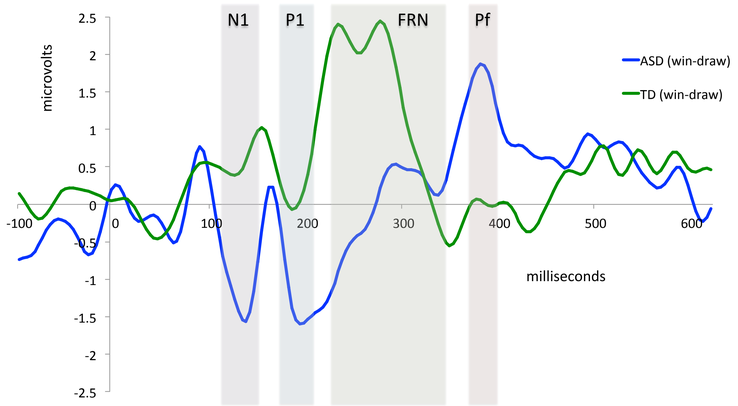


Figure 2: Difference waveforms averaged across FRN montage. TD children (green) show condition differences at the FRN but not the Pf, whereas children with ASD (blue) show differences at the Pf but not the FRN. The Pf is a positive-going potential following the FRN that also occurs over frontocentral leads; the relationship between the FRN and Pf resembles that between the ERN and the Pe. Unlike TD children, those with ASD also differentiate by condition at the N1 and the P1.

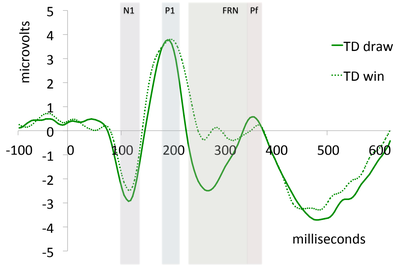


Figure 3: TD waveforms for win and draw conditions averaged across FRN montage.

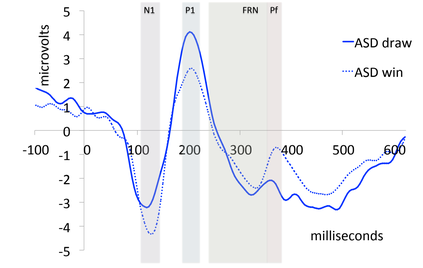


Figure 4: ASD waveforms for win and draw conditions averaged across FRN montage.

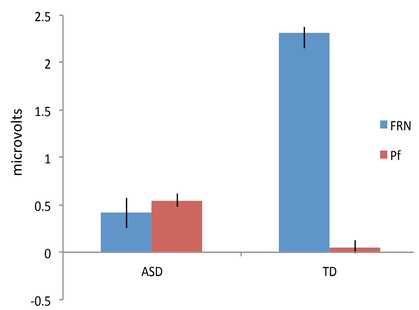


Figure 5: Amplitude differences between conditions at FRN and Pf. Unlike children with ASD, TD children show a significant difference in amplitude by condition at the FRN (draw condition elicits a greater amplitude than win condition). Neither children with ASD nor TD children show significantly different amplitudes by condition at the Pf.

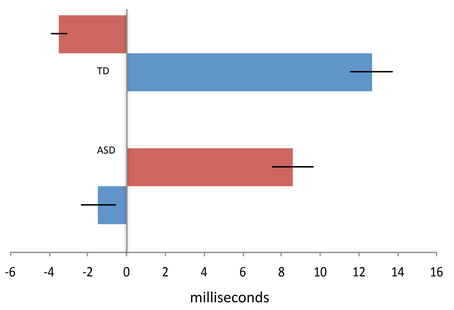


Figure 6: Latency differences between conditions at FRN and Pf. Unlike children with ASD, TD children show a significant difference in latency by condition at the FRN (draw condition elicits a shorter latency than win condition). Children with ASD, but not TD children, show a significant difference in latency by condition at the Pf (draw condition elicits a shorter latency than win condition).

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RESULTS

N1 Amplitude
- Children with ASD showed a greater (more negative) amplitude than TD children across conditions; $p < 0.01$
- *Group*condition interaction; $p < 0.01$*
  - *TD: Draw = Win, ASD: Draw < Win*

N1 Latency
- Children with ASD showed longer latencies than TD children across conditions; $p = 0.03$
- Win condition elicited longer latencies than draw condition across groups; $p < 0.01$
- *Group*condition interaction; $p < 0.01$*
  - *TD: Draw = Win, ASD: Draw < Win*

P1 Amplitude
- *Group*condition interaction; $p = 0.03$*
  - *TD: Draw = Win, ASD: Draw > Win*

P1 Latency
- Children with ASD showed shorter latencies than TD children across conditions; $p < 0.01$

FRN Amplitude
- Draw condition elicited greater (more negative) amplitudes than win condition across groups; $p < 0.01$
- *Group*condition interaction; $p = 0.02$*
  - *TD: Draw > Win, ASD: Draw = Win*

FRN Latency
- Children with ASD showed longer latencies than TD children across conditions; $p < 0.01$

Pf Amplitude
- No differences

Pf Latency
- Children with ASD showed longer latencies than TD children across conditions; $p < 0.01$
- *Group*condition interaction; $p = 0.03$*
  - *TD: Draw = Win, ASD: Draw < Win*

CONCLUSIONS

CONSISTENT WITH OUR HYPOTHESIS, children with ASD and TD children showed different patterns of neural activity during feedback monitoring.

- The draw condition differentially elicited an FRN in TD children but not those with ASD.
- In contrast, Pf latencies for children with ASD, but not TD children, differentiated win versus draw conditions.
- Across conditions, FRN and Pf latencies were slower for children with ASD than TD children.
- Enhanced response at sensory components may reflect differential attunement to sensory information rather than reward value in ASD.

DIFFERENCES IN REWARD PROCESSING between children with ASD and TD children suggest distinct approaches to feedback-based learning between groups.

- Children with ASD may take longer to become aware of subtle differences in feedback; this awareness may be reflected at the later Pf rather than at the FRN.
- The draw instead of lose condition may more precisely reflect subtle distinctions in social feedback. Relative loss, or non-reward, is more ambiguous and more closely resembles typical social feedback than absolute loss, as employed in prior work.
- An alternative interpretation could be that TD children place a greater emphasis on win versus all other non-win conditions, whereas children with ASD place a greater emphasis on loss versus all other non-loss conditions. This interpretation would be consistent in light of both our results and those of Groen *et al.* (2008). To test this, a future study would need to include all three conditions of win, draw, and loss.

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1. Groen, Y., Wijers, A., Mulder, L., Waggeveld, B., Minderaa, R., & Althaus, M. (2008). Error and feedback processing in children with ADHD and children with Autistic Spectrum Disorder: An EEG event-related potential study. *Clinical Neurophysiology, 119:* 2476-2493.
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