1. Introduction

Preference for social engagement at birth indicates that social abilities emerge early and have a deeply seated biological basis (Grossmann & Johnson, 2007). Complex social cognition involving the attribution of mental states, beliefs, and desires is called Theory of Mind (ToM). Recent work suggests that elements of ToM may be present within the first year of life (Onishi & Baillargeon, 2005; Surian et al., 2007; Trauble, Marinovic, & Pauen, 2010; Southgate, Senju, & Csibra, 2007; Kovacs, Teglas, & Endress, 2010; Senju et al., 2010). Yet, much remains unknown about how infants integrate and process complex social information. Here, the objective was to chart changes in the functional patterns of brain activity associated with the emergence of ToM abilities during infancy from birth to 6-7 months.

2a. Methods

Participants: Infants (N = 29) completed Observation 1 between 6-7.5 months (M=6.74 months, SD= 47) and returned 8 weeks later for Observation 2. Each observation consisted of two visits:

Visit 1 - Training: Parents received a binder with toys and were shown how to complete object name training. Each infant received novel toys that varied in shape (beaver, oval, square/circle), color (green/yellow, orange/blue), and name (buggie/bug, bug/bug).

Example: 

![Image of an example with buggie/bug, bug/bug labels]

For three days, parents trained infants twice a day for 10 minutes each session. Training accuracy was confirmed via auditory recorders.

Visit 2 - Test Session: At the lab, infants completed a final brief training session. Event-related potentials (ERPs) and eye movements were acquired while infants observed TV-monitor images. Video images depicted an actress pointing at an object in one of two locations, either retrieving the target or non-target object. The actress responded with congruent (e.g., excitement for retrieving the target object) or incongruent emotional reactions (e.g., confusion for retrieving the target object).

Processing of ERP data: Recorded with 128-channel high-density EEG (NetStation 4.4); Filtered at 0.3-30Hz. Standard artifact detection, bad channel correction, re-referencing to average, and baseline correction applied. Electrode locations were averaged across region (frontal, temporal, parietal, occipital) and hemisphere (left, medial, right).

Amplitudes: Per Kushnirenko et al., 2011, ERPs were extracted for: P150 (40-250 ms), P350 (250-400 ms), N250 (180-280), N450 (350-600).

Hypotheses:

Event 4: Infants will discriminate between retrieving the target object (Object Match) and the non-target object (Object Mismatch). We anticipated that N450 amplitudes will be larger for Object Mismatch across central and parietal medial electrodes at both Observations (Duncan et al., 2009; Molfese, Morse, & Peters, 1990).

Event 5: Infants will discriminate between emotional reactions that are aligned with mental state expectations (Mental State Congruent) and those that violate mental state expectations (Mental State Incongruent). Considering other work implicating the N400 during goal understanding (Reid et al., 2009), we anticipated the N450 would be related to mental state congruence.

3. Results

3a. Event 4: Object reveal

Observation 1: 6 to 7.5 months

<table>
<thead>
<tr>
<th>Object Match</th>
<th>Object Mismatch</th>
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<tbody>
<tr>
<td>N250 250-250 ms</td>
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</tr>
<tr>
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Observation 2: 8 to 9.5 months

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Effect of Observation 1 vs. Observation 2:

N250: no difference
N450: no difference

Effect of Object Match vs. Object Mismatch:

P100: no difference
P350: no difference
N250: no difference
N450: no difference

3b. Event 5: Emotional reaction

Observation 1: 6 to 7.5 months

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Observation 2: 8 to 9.5 months

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Effect of Observation 1 vs. Observation 2:

N250: no difference
N450: no difference

Effect of Mental State Congruent vs. Mental State Incongruent:

P100: no difference
P200: no difference
N250: no difference
N450: no difference

3c. Event 5: Emotional reaction

Observation 1: 6 to 7.5 months

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Effect of Observation 1 vs. Observation 2:

N250: no difference
N450: no difference

Effect of Mental State Congruent vs. Mental State Incongruent:

P100: no difference
P200: no difference
N250: no difference
N450: no difference

4. Conclusions

By 6-7.5 months, infants discriminated between events in which the object matched and did not match the expected target.

We had predicted the N450 would be the primary component to discriminate between object matching outcomes. At Observation 1, there were no significant differences in the N450. However, larger N250 amplitudes across medial occipital electrodes for Match conditions indicated that infants learned object identities.

At Observation 2, the N450 and earlier components (P150, P350) discriminated between conditions. This may indicate that several different brain systems are responding to the violation of object expectation.

By 6-7.5 months, infants discriminated between emotional reactions that were congruent or incongruent with mental state expectations.

At Observation 1, the N450 discriminated mental state congruence, while the mid-latency N250 discriminated mental state congruence at Observation 2. The increased extent and shift in topographic patterns suggest that neural mechanisms are becoming more sophisticated.

Looking at the ERP waveforms, it may be beneficial to consider a late slow wave potential between 500-1000.

Younger infants elicited larger responses to the emotional event than older infants.

Although 6-7.5 month infants discriminated between happy and confused expressions across the waveform, older infants did not have a large response to emotional events. This may indicate that the emotional content might be more of a focus for younger infants than older infants.

Changes to ERP components over development.

Both the increased extent and shift in topographic patterns may suggest that neural mechanisms are changing to become more sophisticated between observations. Using a prior time window, ToM effects shift from the N450 to the earlier N250. However, future analyses should address how these changes are unique from maturation and specific to mental state operations.

5. Summary

These results suggest that infants exhibit the ability to discriminate object and mental state expectations, although younger infants also exhibit strong brain responses to emotional reactions. However, future work should consider whether infants are responding to the actress’s mental state expectations or if responses are also linked to the infant’s own expectations and emotional responses.