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Authors

Soleimani, Zohreh
Tan, Enda
Emberson, Lauren
et al.

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Examining the Robustness of Neural Correlates of Infants' Sociomoral Evaluations

Zohreh Soleimani (zsoleimani@psych.ubc.ca), Enda Tan (enda.tan@psych.ubc.ca), Lauren Emberson (emberson@psych.ubc.ca), and Kiley Hamlin (kiley.hamlin@psych.ubc.ca)
Department of Psychology, University of British Columbia, 2136 West Mall, Vancouver, BC V6T 1Z4, Canada

Abstract

Research has shown that infants prefer prosocial characters over antisocial ones, suggesting that sociomoral evaluation is early-emerging. However, some have argued that infants' preferential responses stem from low-level perceptual processes rather than true social understanding. Using electroencephalography (EEG), past work has suggested that motivational and social, but not attentional, processes are implicated in infants' responses to prosocial versus antisocial acts and individuals, however, the majority of past work utilized a single type of prosocial/antisocial interactions: helping a character to climb a hill. To test the generalizability of past neural findings from the hill paradigm, here we examined infants' responses in a distinct helping/hindering scenario in which a character tries but fails to open a box and is alternatively helped or hindered. Largely replicating past work, infants showed greater activity in social (indexed by the P400) but not attentional (indexed by the Nc) ERP components when seeing hinderers versus helpers, consistent with claims that infants' responses to prosocial and antisocial agents are social. No evidence of differential approach/avoidance motivation during prosocial/antisocial events was found. These findings support the role of social processes in infants' sociomoral evaluations.

Keywords: Infancy, Sociomoral Evaluations, EEG, ERP

Introduction

As adults, effectively navigating our social world is crucial for our survival—we must accurately identify threatening individuals and seek out cooperative ones. Adult research has shown that humans make sociomoral evaluations fast and intuitively, reliably identifying moral transgressions within just 100 ms (Cusimano, Magar, & Malle, 2017; De Freitas & Alvarez, 2018; De Freitas & Hafri, 2024). But where does this vital ability come from?

Recent behavioral research suggests that even preverbal infants are able to perform basic sociomoral evaluations and differentiate between "nice" and "mean" characters (Hamlin et al., 2007, 2010; Hamlin, 2013; Ting et al., 2020; Woo et al., 2022). For instance, early work demonstrated that 6- and 10-month-old infants, after being habituated to a show in which a climbing character tried but failed to reach the top of a steep hill and was alternately helped (pushed up the hill) and hindered (pushed down the hill) by two additional characters, subsequently preferentially reached for the helper over the hinderer (Hamlin et al., 2007). Subsequent experiments revealed independent preferences for helpers over neutral characters and for neutral characters over hinderers at both 6- and 10-months (Hamlin et al., 2007), and that younger, 3-month-old infants looked longer at helpers over hinderers and at neutral characters over hinderers (but, interestingly, not at helpers over neutral characters; Hamlin et al., 2010).

Subsequent studies examined distinct versions of helping and hindering events (for instance, helping versus hindering an agent to open the lid of a box; returning versus stealing a dropped ball) as well as other prosocial and antisocial acts (fair versus unfair distributions; comfort/protection versus physical harm); these studies have similarly shown preferences for prosocial others (Hamlin and Wynn, 2011; Scola et al., 2015; Steckler et al., 2017; Shimizu et al., 2018; Woo et al., 2024; Geraci & Surian, 2011; Geraci et al., 2024; Biro, 2023; Kanakogi et al., 2013; 2017; Lucca et al., 2018). These results suggest that infants' responses are not based on particular low-level perceptual cues present within prosocial versus antisocial events, but extend to the broader class of sociomorally relevant acts. Altogether, findings generated over the past several decades broadly support the conclusion that the ability to sociomorally evaluate others is early emerging.

Over the same time period, however, some studies have failed to replicate infants' prosocial preferences (e.g., Cowell & Decety, 2015; Salvadori et al., 2015; Schlingloff et al., 2020; Vaporova & Zmyj, 2020), and meta-analytic means have generally proven smaller than effect sizes reported in early work, ranging from 58%-68% of infants preferring prosocial others (Margoni & Surian, 2018; Tan, 2024). Most notably, a recent large-scale collaborative replication effort involving 567 (out of 1018 tested) 5.5- to 10.5-month-old infants across 35 research centers worldwide demonstrated that only 49% of infants preferentially reached for helpers over hinderers in the hill paradigm (Lucca, Yuen, et al., 2024). Despite additional positive evidence reported over the same period (e.g., Woo & Spelke, 2023), including with the hill paradigm (Woo et al., 2024), the existence of these failed replications casts doubts on the robustness and generalizability of infants' prosocial preferences.

Aside from questions of replicability, the question of what cognitive processes drive infants' prosocial preferences is a matter of great debate. Most broadly, questions have been raised about the validity of interpreting infants' simple preferential responses as evidence for complex sociomoral understanding (Tafreshi et al., 2014; Dahl & Killen, 2018; Scarf et al., 2012a). These accounts have questioned "rich" interpretations of infants' behavioural preferences, and have offered various "lean" interpretations instead. At a very low-level, Scarf and colleagues (2012a, b) have argued that it is positive and negative non-social perceptual events within and across paradigms (for instance, bouncing and collision in the hill paradigm, valence matching in others), and not pro- and antisociality per se, that drives infants' prosocial preferences

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(cf. Hamlin, 2015). Although behavioral studies have often included non-social controls intended to rule out particular low-level alternatives, which indeed have consistently led to infants choosing randomly, it has frequently been pointed out that is nearly impossible to control for every single potentially relevant factor across distinct conditions in a given paper, and each new paradigm brings new perceptual events that might influence infants' responses in unknown ways (Heyes, 2014; Scarf et al., 2012a, b). Furthermore, infants' limited physical abilities, such as inconsistent reaching behavior prior to 4 months (Hadders-Algra, 2013) as well as perseverative tendencies (Diamond, 1985, Marcovitch & Zelazo, 1999), have led to questions of how consistently and reliably a single reach should be thought to reflect an infants' intentions at any age (Nighbor et al., 2017).

How can we overcome some of the identified limitations of behavioural studies and better understand how infants are processing sociomoral information? The current study utilized electroencephalography (EEG), a neuroimaging technique with very high temporal resolution that allows for examining infants' neural processing at precise points in time and during specific events (Cohen, 2017; Morital, Asada, and Naito, 2016). Most importantly, infant EEG studies to date have revealed various "neural signatures" that are believed to be associated with distinct types of processing and/or motivation (for example, social versus attentional; approach versus avoidance), allowing us to compare infants' neural activity during exposure to prosocial versus antisocial acts and individuals to past work.

To date, four studies have examined infants' neural responses to helping and hindering events; three of which used the "hill paradigm" (Cowell & Decety, 2015; Gredebäck et al., 2015; Tan & Hamlin, 2022). Cowell and Decety (2015) observed relative greater left frontal alpha power when 12- to 24-month-olds viewed hindering versus helping scenarios. Based on past studies suggestive that higher relative left frontal alpha power is associated with avoidance motivation (for review see Harmon-Jones and Gable, 2018; Reznik and Allen, 2018), Cowell and Decety (2015) argued that these patterns suggest that infants experience greater withdrawal motivation when viewing antisocial acts.

Using event-related potential (ERP) methods, Gredebäck and colleagues (2015) investigated six-month-olds' P400 and Nc ERP component's responses to still images of helpful and unhelpful characters following familiarization to helping and hindering events. P400 has been hypothesized to index social perception, more specifically goal-directedness, in infancy (e.g., Bakker et al., 2015, 2016; Galazka et al., 2016; Gredebäck and Daum, 2015); whereas Nc has been hypothesized to index domain-general, attention-related processing (Luyster et al., 2014; for review, see Reynolds & Romano, 2016 and Csibra et al., 2008). Consistent with social (and not attentional) accounts of infants' responses to helpers versus hinderers, Gredebäck and colleagues (2015) observed a distinction between helpers and hinderers in the P400, with greater activity to helpers than to hinderers, but no difference in the Nc component.

Combining methods and analyses from Decety and Cowell (2015) and Gredebäck and colleagues (2015), Tan and Hamlin (2022) explored both frontal alpha asymmetry during helping and hindering events and ERPs to still images of helpers and hinderers in both 6- and 12-month-olds. For frontal alpha asymmetry, they observed greater relative right alpha power during helping events for 6-month-olds, consistent with Decety & Cowell's (2015) results. However, 12-month-olds showed no differential asymmetry to helping versus hindering. Tan and Hamlin (2022) similarly found a differential response to helpers versus hinderers in the P400 component, particularly in the right hemisphere, and no differential response in the Nc. Finally, they found a marginally significant effect in the N290, which is thought to index face processing (for review, see de Haan et al., 2003; Nelson et al., 2006), with more negativity to helpers versus hinderers. Together, these results suggested that infants' differential responding reflects motivational and social, but not attentional, processing.

Finally, Licht et al. (2023) recently examined 6-month-olds' ERP responses to helping and hindering interactions in the so-called "box paradigm" (Hamlin and Wynn, 2011), where a character attempts to open a box but fails. Specifically, they first familiarized infants to two helping and two hindering events, and then assessed ERP responses to a succession of four representative frames of each scenario, time-locking ERP responses to the onset of the first frame (depicting the protagonist's attempt to open the box lid, next to the would-be prosocial or antisocial character. With this design, they observed differential N290 responses over occipital-temporal regions, consistent with Tan and Hamlin (2022), but no effect on the P400, inconsistent with Tan and Hamlin (2022). Additionally, they observed differential responses in the Nc and LPP (indexing late high-level cognitive processes (e.g., Cheng, Chen, & Decety, 2014) components, over central channels. They analyzed the Nc component 350-600 ms after the first (attempt) frame, and the LPP component 650-1200 ms after the (attempt) frame. These findings are somewhat difficult to interpret, however, given the limited familiarization trials (fewer than the minimum required for inclusion in past work) and the decision to time-lock to the still images at the start of the series of images, when no helping or hindering had yet occurred and despite those images changing over time.

Altogether, the EEG studies reviewed above provide some inconsistent evidence for approach-withdrawal motivational responding during the observation of prosocial versus antisocial events, and more consistent evidence suggesting that socially-relevant mechanisms likely underlie infants' responses to helpers versus hinderers. However, several unanswered questions remain. First, to date both frontal alpha asymmetry and differential P400 activity have

only been observed in studies utilizing the hill paradigm, and (for frontal alpha asymmetry) results have been quite inconsistent. Although one study examined generalizability to a different scenario, aside from the N290 it found largely different results (but also included significantly different and somewhat ambiguous methods that necessarily restrict comparability). Thus, a complete understanding of how infants understand and evaluate prosocial and antisocial events more broadly requires further investigation into infants' neural responding to a range of prosocial and antisocial events and individuals but for which methodological decisions are otherwise aligned.

Thus, the present study aimed to further our understanding of the neural processing associated with prosocial and antisocial events/agents through a nearly direct replication of Tan & Hamlin (2022), in which only the choice of prosocial/antisocial scenario differed from the original design. The study design, pre-processing pipeline, and processing parameters followed Tan & Hamlin (2022) and pre-registered in OSF (https://osf.io/v5bjk). Specifically, groups of infants at both 6- and 12-months-of age were shown prosocial and antisocial interactions in the box paradigm (Hamlin & Wynn, 2011) and subsequently viewed still images of the helper and hinderer. During pro/antisocial events, frontal alpha asymmetry was assessed; during still images, social components P400 and N290 as well as attentional component Nc were measured. Based on past work, we hypothesized that infants would show higher relative right frontal alpha power in response to the helping over hindering events (reflecting approach motivation), and that the P400 and N290 components, but not the Nc, would show more positive P400 and less negative N290 in response to images of hinderers versus helpers (reflecting differential social but not attentional processing).

Methods

Participants Thirty-six 6-month-old infants (47% female, mean age = 6.1 months, range = 5.5 - 6.6 months) and thirty-seven 12-month-old infants (37.84% female, mean age = 11.93 months, range =11 -13 months). These age groups were selected in order to enable comparison of the data with previous studies (Gredebäck et al., 2015; Tan and Hamlin, 2022). All infants were full-term (minimum 36-week gestation) and healthy and were recruited from the North American city, mostly from a local hospital or through online registration. For the 6-month group, 36 additional infants were excluded from the final sample for fussiness (N = 14), inattentiveness (N = 15), technical issues, (N = 3), parental interference (N = 1), and excessive artifacts (N = 3). For the 12-month group, 70 additional infants were excluded from the final sample for fussiness (N = 46), inattentiveness (N = 15), technical issues, (N = 7), and excessive artifacts (N = 2). Overall, the attrition rate was 57.5%, which is in the typical range for infant ERP studies (49.16% according to a meta-analysis; Stets et al., 2012). Specifically, previous infant EEG studies focusing on sociomoral evaluations had similar attrition rates (50.17% averaged across four previous papers).

Procedure Infants viewed stimuli on a 23.6" LED screen (Samsung S24B300HL; width: 1920 pixels, 22.4", 51° visual angle; height: 1080 pixels, 13.6", 32° visual angle) while sitting in their parents' laps 60 cm from the screen in a sound-attenuated booth. Parents were instructed to avoid talking to and/or moving their infant during the study to avoid distracting infants and creating noise in the EEG signal. The stimuli were advanced manually from E-Prime 2.0 (Psychology Software Tools Inc., Pittsburgh, PA).

Infants were presented with both familiarization (helping/hindering videos) and test trials (still images of helper/hinderer). One set of familiarizations (3 helping and 3 hindering videos) and test (20 helpful and 20 unhelpful still images) trials was considered a block, and infants were shown blocks until they were no longer attentive or became fussy.

Familiarization Stimuli Each trial began with a 1000 ms ding sound and a 3000 ms black screen, followed by a helping or hindering video featuring hand puppets in an in-lab theater setting. Each video began with a cow puppet attempting to open a clear plastic box containing a colorful book while two other puppets (grey and orange cats) remained motionless in the back corners of the scene. The protagonist unsuccessfully attempted to open the box five times (0-13900 ms). In the prosocial scenario, the helper then ran forward, jumped onto the opposite front corner of the box lid, and helped the protagonist open the box. The protagonist then jumped into the box and lay down on top of the book, achieving its goal, and the helper jumped off the box (13900-19700 ms). In the antisocial scenario, the hinderer jumped onto the box next to the protagonist, preventing the box from opening and the protagonist achieving its goal. The protagonist then jumped off the container and lay down beside it, and the hinderer jumped off the box (13900-19700 ms). Finally, the helper/hinderer exited the stage and the scene paused for 2 seconds, depicting the protagonist having achieved/not achieved its goal (19700-24000 ms).

At the end of each familiarization trial, a black screen was presented until infants were attentive, and then the experimenter played the next trial. Familiarization videos were presented in an alternating pattern, with helping/hindering order (first/second) and helper/hinderer colour (grey/orange) and side (right/left of box) counterbalanced across infants.

Test Stimuli Each trial began with a 1000 ms attention getter, followed by a fixation cross (1200–1400 ms). Then, an image of the helper or hinderer appeared for 2000 ms, followed by a black screen until the infant was attentive. Image order was randomized.

Behavioral Coding Infants' behaviors were videotaped and coded offline. Event markers were added to EEG signals

based on the infants' looking behavior (looking away from and back to the screen). Additionally, major body movements (e.g., crying or touching the EEG cap) and instances of parental interference were marked.

To be included in the final sample, infants had to watch a minimum of 3 helping and 3 hindering familiarization videos, have at least 60 artifact-free segments during the familiarization videos to detect frontal alpha asymmetry, and have at least 10 helper and 10 hinderer artifact-free test trials. On average, participants sat through 2 blocks of trials. Six-month-olds watched an average of 5.31 and 5.33 helping and hindering videos, respectively, and an average of 25 helper and 24 hinderer images. Twelve-month-olds viewed an average of 5.45 and 5.50 helping and hindering videos, respectively, and an average of 20 helper and 20 hinderer images.

EEG Recording and Pre-processing A 64-channel HydroCel Geodesic Sensor Net recorded infants' neural activity, and the signal was amplified by a Net Amps 400 amplifier (Electrical Geodesics, Inc., Eugene, OR). EGI's Net Station v5.2 software was used to collect signals at 1000 Hz. Signals were referenced to the vertex (Cz). All sensor impedances were reduced to below 50 kOhm to ensure high quality signals. Processing of the EEG signal was completed using MATLAB v2021b (MathWorks, Natick, MA), EEGLAB v2022 (Delorme & Makeig, 2004), and ERPLAB v9.10 (Lopez-Calderon & Luck, 2014).

Raw EEG data was pre-processed according to the Maryland Analysis of Developmental EEG (MADE) pipeline for EEG analysis in pediatric populations (Debnath et al., 2020). To begin, the MffMatlabIO EEGLAB plugin was used to transfer raw EEG data, event markers, and channel locations into MATLAB. The data then underwent offline filtering. First, an anti-aliasing filter was applied to the data to remove under-sampled frequencies and the data were adjusted to account for event marker time offsets. Next, the data were down sampled to 250 Hz and were filtered by a high-pass filter (0.3 Hz) and low-pass filter (50 Hz) using the FIRfilt EEGLAB plugin. Before identifying bad channels, the channels located above the ears (E23 and E55) were removed, as the outermost ring of electrodes tends to have poor connections and can be noisy when recording from infants. Then, the FASTER EEGLAB plugin was used to identify and remove the bad channels (those with an absolute Z-score greater than 3).

To reduce other types of artifacts such as eyeblinks and saccades, we used independent component analysis (ICA). First, the original data was copied and passed through a high-pass filter (1Hz), and channels and epochs with excessive artifacts were excluded (see Debnath et al., 2020 for details). ICA was performed on the copy to avoid altering the original data. ICA weights were then applied to the original data to remove movement artifacts from the signal. Individual components (ICs) from artifacts were located using the adjusted-ADJUST script (Leach et al., 2020) and were excluded from the original data. Spherical spline interpolation was used to repair bad channels and the data was re-referenced to the average of all sensors.

EEG Processing Of Familiarization Trials (Frontal Alpha Asymmetry Analysis) Following pre-processing, EEG data from familiarization trials was divided into segments ranging from 2000 ms before the video's start to 2000 ms after the end of the trial (total trial length = 22,000 ms). Trials with less than 70% looking time or containing excessive movement artifacts were rejected through visual inspection. For the alpha asymmetry analysis, 2 additional 12-month participants were included who had watched enough familiarization videos but went on to fuss out during the test (total N= 75).

Videos were separated into 4 phases: Baseline (the black screen preceding the video; -2,000 to 0 ms), Pre-phase (start of video to helper/hinderer movement, 0-13,900 ms), During-phase (helper/hinderer movement to end of helping/hindering action, 13,900-19,700 ms), and Post-phase (end of helping/hindering action to 2000 ms after the helper/hinderer's exit from stage, 19,700-24,000 ms).

Data were divided into 500 ms segments with 50% overlap. A threshold of -200 μV to 200 μV was used for artifact rejection for every segment. The power density of remaining segments was calculated through a Fast Fourier transform with a Hanning window. Average power density was computed across segments and trials for each participant, condition (helping/hindering) and phase (Baseline, Pre-phase, During-phase, and Post-phase). For the 6-month group, on average, there were 543 and 550 usable segments for the helping and hindering videos, respectively. For the 12-month group, the average number of usable segments for helping/hindering videos was 561/567, respectively. To compare the frontal alpha asymmetries, the average power density for right (F4/E60) and left (F3/E12) frontal channels in the 5-8 Hz frequency band were natural log transformed. Then, difference scores were calculated (ln[F4]-ln[F3]).

EEG Processing Of Test trials (ERPs) After pre-processing, the EEG data were segmented from 200 ms preceding the helping/hindering image to 1000 ms after the image appeared. Segments were baseline corrected using the mean amplitude of the 200 ms before the stimulus (during the fixation cross) to account for normal baseline brain activity. Trials were excluded if over 5 channels were outside the artifact threshold (–200 μV to 200 μV) or if infants were looking away from the screen. Then, average N290 and P400 amplitudes were extracted from channels in the occipitotemporal area, from 150-300 ms and 250-400 ms following stimulus onset, respectively (left hemisphere: E31, E33, right hemisphere: E40, E38). The average Nc amplitude was extracted from 400-600 ms following stimulus onset over channels in the fronto-central area (E20, E15, E16, E7, E4, E54, E51, E53, E50).

Results

Prior to ERP and frontal alpha asymmetry analyses, outliers were removed using the rstatix (version 0.7.2) identify_outliers function. Outliers were classified as values 1.5 interquartile ranges (IQRs) above the 75th percentile or below the 25th percentile. We excluded one outlier from the alpha asymmetry analysis. For the 6-month-olds, we excluded one, four, and four outliers from the P400, Nc, and N290 analyses, respectively. For the 12-month-olds, we excluded four, three, and five outliers from the P400, Nc, and N290 analyses, respectively. For analyses of variance (ANOVAs), normality was tested through visual inspection of Q-Q plots of standardized residuals and for the post-hoc analysis, normality was assessed based on the Shaprio-Wilk's tests.

Frontal Alpha Asymmetry We conducted a mixed ANOVA to investigate infants' frontal alpha asymmetry scores from the familiarization trials with condition (helping or hindering) and phase (Baseline, Pre-phase, During phase, and Post-phase) as within-subjects factors and age (6-month, 12-month) as a between-subject factor. Results showed no significant main effects or interactions, *ps* > .05. As pre-registered, to assess if there were any differences in processing during specific phases (Baseline, Pre-phase, During-phase, and Post-phase), frontal alpha asymmetry scores were compared for each condition (helping and hindering) across phases using either paired samples t-tests or non-parametric Wilcoxon-tests, depending on the Shapiro-Wilk normality test. Results showed that frontal alpha asymmetry scores were not significant in any phases (*ps* >.05). These null results were inconsistent with Tan and Hamlin (2022)'s findings with 6-month-olds' differential frontal alpha asymmetry responses to prosocial/antisocial events in the hill scenario, but consistent with their null results in 12-month-olds.

ERPs[1] To examine whether infants exhibited distinct social processing of helper and hinderer images, we conducted separate mixed ANOVAs with 2 (condition: helping or hindering) x 2 (hemisphere: right or left) as within-subject factors and age (age group: 6-month-olds, 12-month-olds) as a between-subject factor for both the P400 and N290 ERP components (Figure 1).

For the P400 response, the mixed ANOVA showed a main effect for age, $F(1, 66)= 31.20$, $p < .001$, $\eta2= .321$, a main effect for condition, $F(1, 66)= 4.35$, $p= .041$, $\eta2= .062$, a main effect for hemisphere $F(1, 66) = 7.08$, $p = .01$, $\eta2 = .097$, and an interaction effect between age and hemisphere, $F(1, 66) = 12.95$, $p < .001$, $\eta2 = .164$. The P400 amplitude was higher for hinderer ($M = 9.43$, 95% CI [7.35 11.5]) than helper ($M = 7.88$, 95% CI [5.65 10.1]) images, higher for 12-month-olds ($M = 14.3$, 95% CI [11.407 17.21]) than 6-month-olds ($M = 3$, 95% CI [.182 5.81]), and higher for the right ($M = 9.79$, 95% CI [7.59 12]) than the left ($M = 7.51$, 95% CI [5.33 9.7]) hemisphere. Additionally, a post-hoc test on the interaction of age and hemisphere revealed that P400 amplitude is higher over the right hemisphere than the left hemisphere for 12-month-olds ($t(66) = 5.36$, $p = 0.001$), and no effect of hemisphere was observed for the 6-month-olds ($p > .05$). This pattern broadly replicates results from Tan and Hamlin (2022) using a distinct helping and hindering scenario.

For the N290, the mixed ANOVA showed a main effect of age, $F(1, 62) = 28.52$, $p < .001$, $\eta2 = .315$, but no main effects of condition, $F(1, 62) = 1.73$, $p = .194$, $\eta2 = .027$ or hemisphere, $F(1, 62) = 2.75$, $p = .103$, $\eta2 = .042$. There was a significant interaction between age and hemisphere, $F(1, 62) = 11.13$, $p = .001$, $\eta2 = .15$. A post-hoc test on the interaction of age and hemisphere revealed that N290 amplitude is higher over the right hemisphere than the left hemisphere for 12-month-olds ($t(66) = 3.58$, $p < 0.001$), and no effect of hemisphere was observed for the 6-month-olds ($p > .05$) (see discussion below). Thus, unlike the current results with the P400 and the marginal N290 effect observed by Tan & Hamlin (2022), we observed no main effect of condition on the N290.

To address potential low-level perceptual explanations for the differential P400 responses between helping and hindering conditions reported above, we conducted a 2 (condition: helping, hindering) × 2 (age group: 6-month, 12-month) mixed ANOVA on the Nc component. We found higher Nc amplitude for the 6-month-olds ($M = -5.71$, 95% CI [-7.6 -3.82]) than the 12-month-olds ($M = -10.41$, 95% CI [-12.2 -8.63]), $F(1, 68) = 28.90$, $p < .001$, $\eta2 = .161$. No main effect or interactions were found for condition, *ps* > 0.05. There was no effect of condition nor interactions, *ps* > 0.05 (Figure 1). This result suggests that infants did not show differences in general attentional processing of helping and hindering still images, consistent with previous findings (Gredebäck et al., 2015; Tan & Hamlin, 2022).

Discussion

The present study aimed to investigate the neural mechanisms underlying infants' prosocial preferences. To explore the generalizability of past findings using the hill paradigm, we examined 6- and 12-month-old infants' EEG responses in a distinct helping/hindering scenario—the box paradigm. To assess whether motivational processes are involved in infants' processing of prosocial and antisocial interactions, we examined frontal alpha asymmetry during prosocial versus antisocial events. Results showed no significant differences in frontal alpha asymmetry based on event type. This finding contrasts with Tan and Hamlin (2022), who observed greater right alpha power (indexing approach motivation) during helping compared to hindering

[1]Following visual inspection of the grand average ERP signal, we found that our preregistered time windows were slightly misaligned (and indeed that they had also been in Tan & Hamlin, 2022): both the P400 and Nc components peaked between 300-600 ms after stimulus onset, consistent with other infant P400/Nc studies (Backer, 2018; Galazka et al., 2016). We then analyzed the data using corrected time windows and found the same, albeit stronger, results.

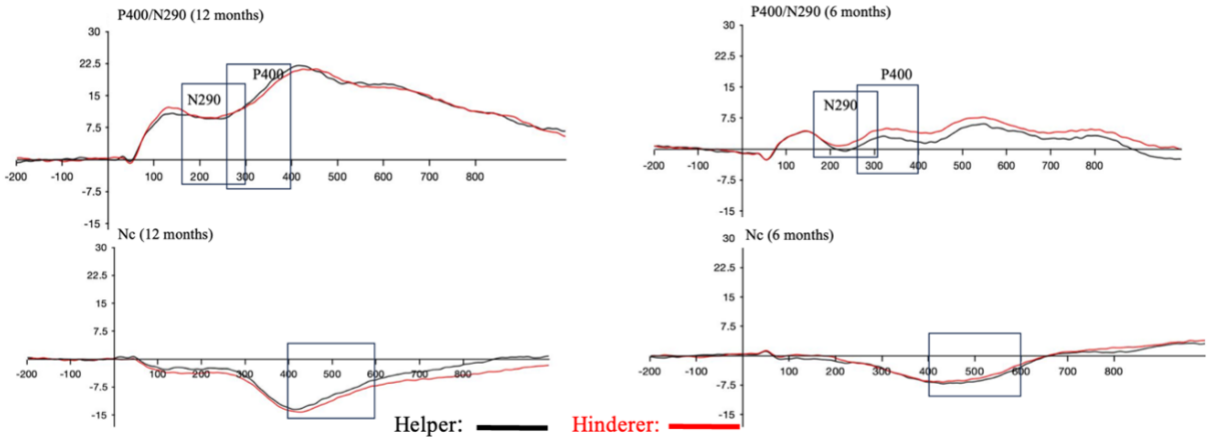


Figure 1: Grand average waveforms of the P400, N290, and Nc ERP components

videos in 6-month-olds, and with Cowell and Decety (2015), who found greater left alpha power (indexing avoidance motivation) during hindering compared to helping videos in 12- to 24-month-olds. However, our results align with Tan and Hamlin's (2022) findings in 12-month-olds, where no significant differences in frontal alpha asymmetry were observed. This inconsistency across studies suggests that any frontal alpha asymmetry response during prosocial versus antisocial events may not be particularly robust, or may not generalize across prosocial/antisocial contexts.

We examined 6- and 12-month-old infants' ERP components related to social processing (P400, N290) and domain-general attentional processing (Nc). Replicating past work, we found that the P400, but not the Nc, responded differentially to still images of helping and hindering characters. Given that the P400 is associated with social processing (Csibra et al., 2008; de Haan et al., 2003), this suggests that infants process these characters differently using social mechanisms, supporting the idea that their social understanding of prosocial and antisocial behavior generalizes beyond a single scenario of the hill paradigm.

We found no significant difference in the N290 component. Although Tan and Hamlin (2022) reported a marginal N290 difference between conditions, this suggests that the effect of character valence on the N290 is weaker than its effect on the P400. One possible explanation, supported by prior infant neurophysiological research, is that the N290 is more specifically sensitive to face processing (for a review, see De Haan, 2003), showing larger amplitudes to faces than to objects (e.g., Conte et al., 2020) and to faces compared to matched scrambled faces (e.g., Halit et al., 2004). In contrast, the P400 appears to be sensitive not only to facial features (for reviews, see Nelson et al., 2006; Csibra et al., 2008) but also to understanding goal-directed action and social valence.

Our findings revealed a lateralization effect in both the P400 and N290 responses, with higher amplitudes over the right hemisphere. This aligns with Tan and Hamlin (2022), as well as prior research on infants' perception of goal-directed actions (e.g., higher P400 for congruent vs. incongruent pointing; Gredebäck et al., 2010). Similarly, higher N290 amplitudes over right-hemisphere channels have been reported in infant face processing studies (e.g., Johnson et al., 2005). That said, consistent with previous studies, we did not find a significant interaction between hemisphere and condition, suggesting that this lateralization effect is not modulated by condition.

We found stronger P400 responses to hinderers than to helpers. These results are consistent with previous behavioral research suggesting that infants are more attuned to negative social agents and outcomes than to positive ones (Hamlin & Baron, 2014; Hamlin et al., 2010), as well as with a broader negativity bias across development (Vaish, Grossmann, & Woodward, 2008) The current findings, along with ERP studies showing larger P400 amplitudes for agentive acts (e.g., goal-directed vs. non-goal-directed actions, congruent vs. incongruent actions; Bakker et al., 2015, 2016; Gredebäck et al., 2010), suggest that infants may show stronger P400 responses to stimuli that evoke a greater sense of agency. More broadly, our results support the idea that negative actions and agents are more likely to trigger agency perception and mentalizing, potentially due to the importance of identifying harmful individuals (Woo et al., 2023). Overall, our findings contribute to the growing evidence that infants engage in sociomoral evaluation from an early age. Future research should explore other sociomoral events (e.g., fairness, harm) to further examine the breadth and robustness of these effects.

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