

Infants' neural responses to sociomoral scenarios via EEG

by

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF ARTS

in

THE FACULTY OF GRADUATE AND POSTDOCTORAL STUDIES

(Psychology)

THE UNIVERSITY OF BRITISH COLUMBIA

(Vancouver)

August 2023

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in Psychology

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Abstract

A growing body of research has shown that preverbal infants prefer prosocial to antisocial characters, suggesting that the ability to sociomorally evaluate others is early emerging. However, some argue that infants' responses within these studies reflect low-level perceptual processes rather than social understanding of the events. Using electroencephalography (EEG), the purpose of this research was to address this alternative explanation by examining 1) specific neural signatures that have been associated with social (indexing by P400 and N290 ERP components) versus lower-level attentional processing (indexing by Nc ERP component) and 2) motivational processes involved in infants' prosocial preferences (indexing by frontal alpha asymmetry for approach/avoidance motivation). Thirty-six 6-month-old infants watched a helping/hindering scenario, in which a character tries but fails to open a box, then is alternatively helped or hindered in opening the box lid. Infants showed greater amplitudes in the P400 component as well as greater N290 component over the right hemisphere channels to hinderers versus helpers (indexing social perception); in contrast, no significant differences were observed for the Nc component (indexing attentional allocation). No motivational processes were observed when infants viewed helping versus hindering videos. Overall, our findings provide evidence for the presence of social processes in infants' responses to sociomoral actors, suggesting that infants' responses to sociomoral events are unlikely to be attributable to attentional differences.

Lay Summary

Do infants have sociomoral understanding? Previous studies have suggested that even before they can talk, infants may have a sense of who is nice and who is not. However, some believe that infants' sociomoral evaluations might be based on basic visual differences rather than a true social understanding of a given social interaction. This thesis investigates the nature of infants' responses to sociomoral interactions using a brain-measuring technique called electroencephalography (EEG) on 6-month-old infants. We discuss the implications of our findings regarding the neural mechanisms supporting infants' prosocial preferences.

Preface

This thesis is an original, unpublished intellectual product of the author, Z. Soleimani. The research was conducted by the author at the University of British Columbia under the supervision of J. K. Hamlin, who was involved in the research design, data analysis, and research design. All work, data collection procedures, and methods were approved by the University of British Columbia's Research Ethics Board (H10-01808, "Early Understanding of the Physical and Social Worlds").

Table of Contents

Abstract	iii
Lay Summary	iv
Preface	v
Table of Contents	vi
List of Figures	vii
Acknowledgments	viii
Dedication	ix
Introduction	1
Behavioral Evidence	1
The Nature Of Infants’ Sociomoral Responses	3
What Neural Mechanisms Lead To Infants’ Social Preferences?	8
Applying The Logic Of Neural Signatures To Infants’ Sociomoral Evaluations	12
The Present Study.....	14
Methods	16
Participants	16
Procedure And Stimuli	17
EEG Recording and Pre-processing.....	20
EEG Processing.....	21
Results	25
ERPs Analysis	25
Frontal Alpha Asymmetry Analysis	29
Discussion	31
Bibliography	40

List of Figures

Figure 2. 1. Schematic diagram of the stimuli.....	19
Figure 2.2. Channels used for frontal alpha asymmetry, P400, N290, and Nc analyses	22
Figure 2.3. Phases of familiarization trials (the helping condition)	23
Figure 3. 1. P400 amplitude in helper and hinderer condition	26
Figure 3. 2. P400 amplitude in helper and hinderer conditions over the right and left hemispheres	27
Figure 3. 3. N290 amplitude in helper and hinderer conditions over the right and left hemispheres	28
Figure 3. 4. Nc amplitude in the helper and hinderer conditions	29
Figure 3. 5. Frontal Alpha Asymmetry (Right Hemisphere – Left Hemisphere)	30

Acknowledgements

First, I would like to thank my advisors, Kiley Hamlin and Lauren Emberson, for encouraging my research and allowing me to grow as a researcher. I would specially like to thank Kiley for her support and guidance on this project particularly.

Thank you to my committee member, Janet Werker, for your mentorship and collaboration. You encouraged me to think about my research interests through different perspectives. Your feedback has been invaluable.

To, Enda Tan, thank you for answering my endless questions. I do not know what I would have done without your advice.

Thank you to members of the Centre for Infant Cognition and the Baby Learning Lab: lab managers and all research assistants, in particular, Sarah Wissmann, Kaye Chan, and Maryam Khan for their support throughout this journey.

To Francis Yuen, thank you for sharing your skills and experience with me.

Thank you to the participants and their families for taking the time to help further this research. None of this work would have been possible without you.

To the friends who provided me with emotional support, thank you for your words of encouragement and for all you have done for me.

Finally, I would like to thank my family for giving me love and support to pursue my passion and for motivating me to continue. I am all that I am because of you.

To my light, the messenger of all goodness, who came to perfect the noble character-

The Prophet Muhammad (SAW)

Introduction

As adults, we navigate social interactions surrounding us to identify friendly individuals that we can cooperate with and distinguish them from unfriendly individuals to avoid. It's important for our survival to recognize those who can offer us care and support and those who may harm us. But where does this ability come from?

One way to approach this question is to study human infants well before they have gained social norms and cultural values. If infants show early signs of distinguishing between “bad” and “good”, it suggests that some aspects of moral capacities may be hardwired into human nature. A growing body of research has shown that infants are selectively sensitive to social cues in their environment. Specifically, they are sensitive to the valence of social interactions and have shown to prefer prosocial over antisocial characters (for review, see Woo et al., 2022). However, some argue that infants' sociomoral evaluations are not adult-like until at least their fourth birthday (e.g., Dahl & Killen, 2018; for review, see Killen & Smetana, 2015) and/or can be attributed to physical perceptual processing of a given interaction (e.g., Scarf et al, 2012), suggesting that infants' evaluations of sociomoral interactions do not stem from a truly social understanding of the acts. To date, less research has examined the mechanisms underlying infants' sociomoral evaluations, rendering their exact nature unclear. The current research aims to provide some insight to this ongoing debate by examining the brain mechanisms that support infants' prosocial preferences.

Behavioral Evidence

A wealth of behavioral research suggests that even preverbal infants are able to perform basic sociomoral evaluations, which some have argued to be a rudimentary form of morality (Hamlin et al., 2007, 2010; Hamlin, 2013; Ting et al., 2020; Woo et al., 2022).

Infants' sociomoral evaluations were first investigated via a helping/hindering scenario using the "hill paradigm" (Hamlin et al., 2007, adopted from Kuhlmeier et al., 2003). In the hill paradigm, a circular agent character with eyes attempts to reach the top of a hill unsuccessfully. During helping events, a helpful character (either a square or triangle; also with eyes) pushes the climber to the top of the hill, facilitating its goal; during hindering events, the hindering character pushes the climber to the bottom of the hill, blocking its goal. After habituating to helping and hindering hill events, infants as young as 3-6 months of age have been shown to look longer to the helpful character over the hindering character (Hamlin et al., 2007, 2010). After developing the motor ability to reach for objects, 6- and 10-month-olds were shown to preferentially reach for a helper over a hinderer, a helper over a neutral character, and a neutral character over a hinderer (Hamlin et al., 2007; see also Hamlin, 2015; Lee et al., 2015, 2020; cf. Schlingloff et al. 2020). Thus, infants' looking and reaching behaviours for helpers and hinderers in the hill paradigm suggest that preverbal infants have an inclination for helpful characters and against hindering ones.

Subsequent studies using distinct helping/hindering scenarios have shown similar results. For example, Hamlin and Wynn (2011) reported that 3- and 5-month-old infants displayed a preference for a character who returned a ball to an agent who lost it, over a puppet who stole the ball away (the "ball paradigm"; see conceptual replication by Scola et al., 2015). They also found that 5- and 9-month-old infants preferred a character who helped another character open a box to retrieve a desired toy over a character who slammed the box lid closed thereby preventing the character from obtaining the toy (the "box paradigm"; see replication by Steckler et al., 2017; and failed replication by Salvadori et al., 2015). Additionally, in a cross-cultural study conducted by Shimizu et al. (2018), Japanese and European American infants

aged 6 to 18 months were compared in terms of their sociomoral evaluations using the ball and the box paradigms. The study found no cultural differences between the two groups in terms of their preference for prosocial agents over antisocial agents. Altogether, these findings suggest that preverbal infants are able to distinguish between helpful and unhelpful characters, and prefer helpful ones.

Beyond helping and hindering, over the past two decades infants' sociomoral evaluations have been studied through various distinct types of sociomoral scenarios, including fair versus unfair distributions (Burns & Sommerville, 2014; Lucca et al., 2018) and protecting versus harming (Kanakogi et al., 2013; 2017) events. They have also utilized several different research methods, such as natural observations (for review, see Tomasello & Vaish, 2013), laboratory experiments (Kanakogi et al., 2022; for review, see Hamlin & Sitch, 2020; Ting et al., 2020), and computational simulations (Benton & Lapan, 2021; Hamlin et al., 2013). Overall, a meta-analysis conducted by Margoni & Surian (2018) analyzed 26 published and unpublished studies featuring different types of sociomoral scenarios and found that 68% of infants between the ages of 4- and 32-months old demonstrated a preference for the prosocial character in a variety of sociomoral situations. Following this meta-analysis, at least 15 additional papers have investigated infants' sociomoral evaluations, and 13 have provided positive evidence for infants' prosocial preferences (for review, see Woo et al., 2022). Altogether, these findings support the conclusion that the ability to sociomorally evaluate others is early emerging.

The Nature Of Infants' Sociomoral Responses

The studies discussed thus far have all utilized behavioural measures to assess social evaluations. Although behavioural evidence has demonstrated and undoubtedly provided some insight into the nature of infants' preferences, questions have been raised about the validity of

interpreting infants' looking and reaching behaviours as evidence for complex sociomoral understanding and evaluation so early in development. These accounts have questioned "rich" interpretations of infants' behavioural preferences, and have offered various "lean" interpretations instead.

For instance, one possibility is that infants' preferences for helpful over unhelpful characters are not based on the social aspects of the characters' interactions at all, but instead on low-level physical differences that exist between helper and hinderer displays. For example, Scarf et al., (2012) suggested that positive and negative perceptual events in the hill paradigm (e.g., bouncing and collision), and not pro- and antisociality, determined infants' preferences. They provided positive evidence for their claims, ultimately concluding that infants' responses in sociomoral evaluation tasks reflect low-level perceptual processing rather than sociomoral evaluation (cf. Hamlin, 2015).

In a similar vein, some have argued that infants' preference for purportedly prosocial others stems from associative learning processes that extract common physical features of social interactions. Using a connectionist computational model, Benton and Lapan (2021) showed that infants' everyday experiences allow them to associate agents engaging in concordant action (moving like and with each other, as prosocial agents often do) with the capacity for interaction more generally, and to associate agents engaging in discordant action (moving unlike or opposed to each other, as antisocial agents often do) as lacking this capacity. Benton and Lapan (2022) conducted four distinct simulations, wherein their model, trained only on the association between concordant action and capacity for interaction, tended to "select" the helpers in various helper/hinderer scenarios. Based on these results, Benton & Lapan (2022) argued that infants' preferences for helpers in helping/hindering studies are based on "capacity for interaction," and

not prosocial behaviour, and that this capacity is based on low-level associative learning, not early-developing sociomoral abilities.

Alongside these low-level interpretations of infants' preferences for helpers has come behavioural evidence that they instead may be based on genuine sociomoral processing (Tan & Hamlin, 2022; Woo & Spelke, 2023; for review, see Hamlin, 2013; Woo et al., 2022). For example, to rule out the low-level perceptual account, Hamlin et al., (2007, 2010; see also Hamlin & Wynn, 2011) examined infants' evaluations of non-social control conditions, in which protagonists are inanimate objects (e.g., entities without agency cues such as eyes and that do not perform self-propelled actions) that are acted upon by agentive characters who perform the same actions as helpers/hinderers do in the social conditions (e.g., pushing up versus down hills, opening versus closing boxes). Because inanimate objects are unable to perform goal-directed actions or be helped/hindered, infants should not attribute pro/antisociality to these acts. In contrast, if infants' responses are solely influenced by specific perceptual features of helping and hindering displays, infants should still exhibit a preference for the "prosocial" characters in the control conditions, because perceptual features of the original scenario are largely maintained. Critically, infants have not shown a preference in any non-social control conditions, suggesting that infants' processing of social conditions reflects (at least) social understanding of the events as opposed to mere perceptual processing.

Another area of research that supports rich interpretations of infants' understanding of sociomoral events involves investigating whether and how mentalizing informs infants' preferences for prosocial others. For instance, if infants' evaluations of prosocial and antisocial characters stem from their representations of characters' mental states, as opposed to the physical actions or outcomes that occur in a scene, it would suggest that infants' preferences

cannot be attributed solely to superficial features of the social interaction. Supporting this idea, Tan and Hamlin (2022) examined whether 5-month-olds' looking behaviours toward the goal of the climber relate to their helper preferences in the hill paradigm using eye-tracking. Results showed that infants who looked longer at the climber's goal (the top of the hill) as it tried but failed to reach it were also more likely to look at the helper over the hinderer during preferential looking trials. These results suggest that infants' preferences for helpers in sociomoral contexts relate to their understanding of the goals of others' actions, consistent with a high-level account.

Moreover, Woo & Spelke (2022) examined whether infants' social preferences are influenced by their emerging understanding of the protagonist's goal in a variation of the box paradigm in which there were two possible goal objects inside two different boxes. Specifically, the protagonist first demonstrated a goal to open box A, containing toy A; the location of toy A was eventually switched to box B and two "helpers" opened each box in turn, allowing the protagonist to access the toy inside. Based on work demonstrating that older, but not younger, infants understand the second-order goal of opening a box to obtain a toy (Sommerville & Woodward 2005), they found that 8- and 15-month-olds preferred the character who helped the protagonist achieve whatever goal they inferred the protagonist to have: for younger babies, once again opening box A (now containing toy B); for older babies, once again accessing toy A (now inside box B). Importantly, an additional condition showed that 8-month-olds preferred the opener of box B (containing previously-accessed toy A) when they had been shown directly that the protagonist's goal was toy A. Together, these results cannot be accounted for by perceptual processing (e.g., Scarf et al., 2012) or a preference for concordant action (e.g., Benton & Lapan, 2022), and suggest that infants' prosocial preferences stem from their understanding of mental states. This supports the possibility that infants' evaluations and

preferences reflect their representation of social aspects of the given interaction, strengthening the notion that fundamental forms of sociomoral evaluations may emerge early in development.

Other evidence that infants' responses to prosocial/ antisocial interactions and agents reflects genuine sociomoral responding comes from research that has examined whether infants' sociomoral preferences predict their tendency to do prosocial behaviors in other contexts (e.g., Dahl et al., 2013) or later in development (e.g., Tan et al., 2018). If infants consistently exhibit similar responses to sociomoral scenarios and sociomoral behaviors across distinct contexts, it would support the possibility that their preferences for prosocial individuals are driven by genuinely (pro) social processes. Several studies have found positive evidence for such a relationship. For instance, Schmidt & Sommerville (2011) found that 15-month-old infants who showed greater sensitivity to fair distributions (e.g., splitting 4 crackers by 2:2 versus 0:4 ratio) were more likely to engage in prosocial sharing behavior. Relatedly, Dahl et al. (2013) found that 16-27-month-olds who expected the recipient of antisocial behavior to stop interacting with the antisocial experimenter (i.e., looked longer at the continuation of the antisocial interaction) were more likely to help the prosocial agent than those who did not show this expectation in subsequent tests. Together, these studies suggest that infants' responses in sociomoral studies may reflect genuine sociomoral understanding and evaluation.

Although behavioral studies have undoubtedly provided insight into the nature of infants' responses to sociomoral events, there are nevertheless some limitations inherent to a behavioural approach. First, comparing social and non-social control conditions brings inherent challenges, given that it 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. Furthermore, behavioural

studies are limited by infants' own limited physical abilities. For example, reaching behaviour does not consistently develop until infants are about 4 months of age, which makes reaching an inconsistent measure before, and presumably for some period after, that age (Hadders-Algra, 2013). It is also unclear how consistently and reliably a single reach reflects an infants' intentions. Indeed, using a repeated choice paradigm, Nighbor and colleagues (2017) examined 5- to 9-month-old infants' sociomoral preferences in a helping/hindering scenario. Although their results replicated past studies on the first-choice trial (65% of infants chose the helper puppet on the first trial), only 38% of infants chose the same helper puppet in a second-choice presentation over changes in the puppets' locations, suggesting that a single-choice paradigm may not reveal infants' stable preferences for one character over another. Adding to the ambiguity are well-documented tendencies for perseveration over repeated motor responses in infants in the first year of life (Diamond, 1985, Marcovitch & Zelazo, 1999).

Behavioural studies are also restricted in that infants' sociomoral evaluations cannot be assessed in real time. That is, behavioural measures such as preferential looking and reaching for prosocial versus antisocial characters can only be examined after a sociomoral scenario has been shown repeatedly; thus, results can conceivably be influenced by various unknown factors such as individual infants' memory, their level of comfort and engagement during the preference procedure, their physical abilities, etc.

What Neural Mechanisms Lead To Infants' Social Preferences?

How can we overcome some of the identified limitations of behavioural studies and better understand exactly how infants are processing sociomoral scenarios and agents? One useful tool would be to investigate infants' neural activity as they both observe sociomoral acts and subsequently encounter prosocial and antisocial others. Although every individual

methodology comes with its own limitations, neuroimaging techniques, in particular electroencephalography (EEG) with its high temporal resolution, are relatively unique in that they can enable researchers to delve into infants' neural processing at precise points in time during specific events (Cohen, 2017). More importantly, neuroimaging techniques have revealed various “neural signatures” associated with distinct types of processing, allowing us to (for example) distinguish between social versus attentional processing.

A key neural signature thought to indicate the presence of social processing is the N170 event-related potential (ERP) component. Specifically, studies with adults demonstrate that the N170 ERP component is sensitive to the presence of faces, and its amplitude is modulated by face inversion (e.g., Jacques et al., 2007), facial race (e.g., Vizioli et al., 2010), and emotional expression (e.g., Blau, et al., 2007; Righart & De Gelder, 2008). Although the N170 has only been shown in adults, it has been shown to be equivalent to the N290 and P400 ERP components in infants (for review, see de Haan et al., 2002; Nelson et al., 2006). Indeed, infant neurophysiological studies have shown that, similarly to the adult N170, the infant N290 ERP component is sensitive to faces versus objects (e.g., Conte et al., 2020), object congruent versus object-incongruent gaze shifts (e.g., Senju et al., 2006), directed versus averted gaze (e.g., Farroni et al., 2004) as well as emotional expressions (Xie et al., 2019) (for review see, Csibra et al., 2008).

In addition to the N290, the infant P400 component has been shown to be sensitive to other forms of visual social information. For instance, the P400 is elicited more in response to biological than to non-biological motion (Reid et al., 2006); and more to grasping, a ‘give-me’ hand gesture (Bakker et al., 2015, 2016), pointing (Gredebäck et al., 2010; Melinder et al.,

2015), and chasing (Galazka et al., 2016) than to various matched non-goal-directed action control conditions.

Adding to the argument that the P400 and N290/N170 components reveal social processing is source-localization work linking these components to activity in the superior temporal sulcus (STS; Dalrymple et al., 2011; Gredebäck and Daum, 2015; Gredebäck et al., 2010; Itier and Taylor, 2004; Puce et al., 2003) as well as the fusiform gyrus (Richards et al., 2018). The STS in particular has been shown to be a key brain region involved in social processing in adults (e.g., Deen et al., 2015; Lee et al., 2010; Puce et al., 1998; Moll et al., 2005). For instance, using functional magnetic resonance imaging (fMRI), Puce et al (1998) were among the first in identifying functional activity in the posterior temporal area of the STS in response to social actions, particularly eye and mouth movements. Similarly, Pelphrey et al. (2005) observed STS activation for dynamic biological motion, and Lotze et al. (2006) found that the STS exhibited distinct responses to expressive hand gestures (e.g., waving) compared to isolated hand movements (e.g., using a key). Together, these studies suggest that STS shows higher activation when stimuli have greater social relevance.

The STS may be particularly activated by social interactions (e.g., Deen et al., 2005; Isik et al., 2017; Walberin et al. 2018; Farris et al, 2022). For example, Walbrin and colleagues (2018, see also 2020) investigated adult brain networks specialised in processing social interactions via fMRI. Using point-light human figure stimuli, they found that the right pSTS as well as neighbouring temporo-parietal junction (TPJ) are maximally activated in response to dyadic interactions compared to non-interactive dyads. Additionally, they examined the response of the posterior superior temporal sulcus region to stimuli that involved geometric shapes (specifically, two circles) moving in a manner similar to human interaction. The findings

showed a similar pattern of results, indicating that the activation of the right posterior STS is influenced by the content of actions (i.e., social interactions vs nonsocial stimuli) regardless of whether they are performed by human figures or geometric shapes (see also Isik et al., 2017).

In addition to adult studies, a growing body of research with infants within the age range of 4 to 24 months has shown that the pSTS, along with the TPJ and medial prefrontal cortex (mPFC) are specialised in processing social information (for review see McDonald & Perdue, 2018 and Grossman, 2015; Lloyd-Fox et al., 2009, 2014). Using functional near infrared stereoscopy (fNIRS), studies have revealed that the pSTS is activated while infants process dynamic actions performed by human actors such as peek-a-boo (Farroni et al., 2013; for cross-cultural study, see Lloyd-Fox et al., 2016) or performed by artificial agents such as the geometric shapes (Biondi et al., 2021). Typically, pSTS selectivity is strongest in the right hemisphere in development (e.g., Wellbutrin et al., 2020). The STS is also selective to congruent social actions (human making human movements vs. robot making human movements (Grossmann et al., 2013), to images of faces (Kobayashi et al., 2016), and to mutual gaze (Grossmann et al., 2008).

Taken together, these studies suggest that the STS and its associated neural signatures, particularly the P400 as well as N290 ERP components, consistently emerge as key factors in the investigation of social processing in both adults and infants. In contrast, the Nc, which occurs 400-850 ms after stimulus onset over the frontal-central regions (Luyster et al., 2014; for review, see Reynolds & Romano, 2016 and Csibra et al., 2008), is likely indicative of nonsocial, perceptual or attentional processing. For instance, Nc amplitude has been found to be greater to infrequent or novel than frequent stimuli (e.g., Ackles & Cook, 2007 and greater during periods of consistent attention (Richards, 2003).

Apart from the neural signatures indexed to social versus attentional processing, there is an EEG signature related to motivational processing, known as frontal alpha asymmetry. Frontal alpha power is assessed by comparing alpha power activity levels (8–13 Hz for adults and 5-8 Hz for children) between left and right frontal brain areas. Past studies in infants and adults have shown that relative right and left frontal alpha power are associated with positive emotion and approach motivation and negative emotion and avoidance/withdrawal motivation, respectively (Buss et al., 2003, Davidson et al., 1990; Tomarken et al., 1992; for review, see Reznik & Allen, 2018). For instance, Fox & Davidson (1987) showed that 10-month-old infants displayed increased right alpha power (indexing approach motivation) at a moment during which their mothers engaged with them relative to merely entered the room; other work demonstrated increased right alpha power to happy versus sad facial expressions (Davidson & Fox, 1982).

Other studies suggest that higher relative right frontal alpha power is specifically associated with approach motivation, irrespective of the emotional valence of an event. For example, some studies have found that offensive anger, which is associated with aggressive approach tendencies, is correlated with higher right frontal alpha power in both adolescents (e.g., Harmon-Jones & Allen, 1998) and adults (e.g., Keune et al., 2012).

Applying The Logic Of Neural Signatures To Infants' Sociomoral Evaluations

Given what is known about how distinct neural signatures can be used to indicate whether and how infants are processing social stimuli, recent studies have attempted to apply this logic to infants' sociomoral responding. To date, three studies have examined this question;

all have explored infants' neural responses to helper and hinderer events in the "hill paradigm" (Cowell & Decety, 2015; Gredebäck et al., 2015; Tan & Hamlin, 2022).

In the first study, Gredebäck and colleagues (2015) investigated six-month-olds' P400 ERP component's responses to the still images of helpful and unhelpful characters following familiarization to helping-hindering videos. Consistent with social accounts of infants' responses, they observed a distinction between helpers and hinderers in the P400, with greater activity to helpers than to hinderers, but no difference in the Nc. In the second study, Cowell & Decety (2015) observed relative greater left frontal alpha power when 12- to 24-month-olds viewed hindering versus helping scenarios, suggestive of greater withdrawal motivation when viewing antisocial acts. Finally, Tan & Hamlin (2022) explored both ERPs to still images of helpers and hinderers and frontal alpha asymmetry during helping and hindering in both 6- and 12-month-olds, and 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; they also found a marginally significant effect in the N290. For frontal alpha asymmetry, they observed greater relative right alpha power during helping events, consistent with Decety & Cowell's (2015) results.

Taken together, these three EEG studies provide evidence that approach-withdrawal motivation and socially-relevant mechanisms underlie infants' responses to the hill paradigm (Cowell & Decety, 2015b; Gredebäck et al., 2015; Tan & Hamlin, 2022). Although these findings are promising, many unanswered questions remain. First, results across studies showed some inconsistencies that require further investigation. Further, and most importantly, all past work has used the hill scenario. Thus, it is possible that patterns of neural activity observed in previous studies were specific to hill helping and hindering events, rather than patterns of

responding to helping versus hindering (or indeed to prosocial versus antisocial) actions and individuals more broadly. Thus, a complete understanding of how infants understand and evaluate prosocial and antisocial events requires further investigation into infants' brain activity in response to a range of prosocial and antisocial events and individuals.

The Present Study

The present study investigated the consistency and generality with which infants' processing of sociomoral scenarios and characters involves social and motivational processing. Specifically, the study investigated the generalizability of previous findings to a new helping-hindering interaction, namely the box paradigm, in which a character attempts to open a box but fails. Obtaining similar results to those observed in the hill paradigm in a distinct helping and hindering scenario would strengthen the evidence for infants' social understanding of sociomoral events.

In the current study, 6-month-old infants (total $N = 36$) were familiarized with the box scenario, in which a protagonist tries but fails to open a box containing an attractive toy and is alternatively helped and hindered in its goal. The age group was selected in order to enable comparison of the data with previous studies (Gredebäck et al., 2015; Tan and Hamlin, 2022). Infants' right and left frontal alpha power was assessed during the familiarization trials to investigate their motivational states. The P400, N290, and Nc ERP components were compared as infants were shown images of the helper and hinderer in order to detect the presence or absence of differential social and attentional processing. The design and analysis strategies of the study were pre-registered on OSF – <https://osf.io/v5bjk/>.

Based on past work using the hill paradigm, we predicted that both motivational and social processing are involved in infants' sociomoral responses. Specifically, we hypothesized

that infants would show higher relative right frontal alpha power in response to the helping over the hindering scenarios, as was previously observed with the hill paradigm (Cowell & Decety, 2015; Tan & Hamlin, 2020). Additionally, as in Tan & Hamlin (2022), we predicted that the P400 and N290 components would have higher amplitudes in response to still images of hinderers compared to helpers, but no difference in the Nc component, indicative of social but not attentional processing.

Methods

Participants

Participants were 6-month-old infants ($N = 36$, 47% female, mean age = 6.1 months, range = 5.5 - 6.6 months). All infants were full-term (minimum 36-week gestation) and healthy and were recruited from the Metro and Greater Vancouver area, mostly from a local hospital or through online registration. Participants were of European (38.88%), East and South Asian (22.21%), West Asian (7.89%), multiracial (11.11%), African (2.7%), and other (19.44%) descent, which is reflective of the local population. Also, our sample was very well educated, consisting of 83.33% of families with at least one parent with at least a Bachelor's degree. 36 additional infants were excluded from the final sample for fussiness ($N = 17$), inattentiveness ($N = 15$), technical issues, ($N = 3$), and parental interference ($N = 1$). Overall, the attrition rate was 50%, which is typical in 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. For example, Gredebäck et al. (2015) and Tan & Hamlin (2022) reported a rate of 43% and 44% for 6-month-olds, respectively, and Cowell & Decety (2015) reported a rate of 65.75% for 12- to 24-month-olds.

The target sample size ($N=32$) was chosen to result in a similar sample size to Tan & Hamlin (2022) to allow for more effective comparisons. Also, 32 is on the upper-end of conventional sample sizes for infant studies (e.g., for review, see Oakes, 2017). We aimed for a sample size of 32, but during preprocessing, we found four additional data points with a sufficient number of trials to retain; these are included in our subsequent analyses. The decision to include these participants was made before data analysis. Upon completion, families received a certificate of participation and a small toy or t-shirt. The study was approved by the

university's Research Ethics Board. The target sample size, inclusion criteria, procedure, and analysis plan were pre-registered on the Open Science Framework (OSF).

Procedure And Stimuli

Aside from the content of the stimuli, study procedures replicated Tan & Hamlin (2022). 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 and test trials. One set of familiarization (3 helping and 3 hindering videos) and test (20 helpful and 20 unhelpful still images) trials was considered a block (Figure 2.1). Each familiarization trial started with a ding sound (1000 ms) and a black screen (3000 ms) followed by a helping or hindering video. The familiarization stimuli (helping and hindering videos) were puppet shows filmed at an in-lab theater surrounded on three sides by black curtains. All events began with a protagonist (a black and white cow puppet) attempting to open a clear plastic box (35/10/25 cm) containing a colourful book. At the beginning of each familiarization video, the protagonist appeared from behind the back curtain in the middle of the stage; the helpful and hindering characters rested motionless at the back corners of the stage. The protagonist then moved to one side of the box resting at the centre of the stage, and leaned down to look twice at the book inside it. The protagonist then jumped onto the front corner of the box and unsuccessfully attempted to open the box five times. On each attempt, the box lid opened only part way and then closed again. The first two times were

slower and the lid slammed closed and then the last three were faster and the lid didn't contact the rest of the box (0-13900 ms). In the prosocial scenario, the helpful character resting at the back corner of the stage behind the other side of the box ran forward, jumped onto the other front corner of the box lid, and helped the protagonist pull the box open. The protagonist then jumped into the box and lay down on top of the book, achieving its goal, and the helpful character jumped off the box (13900-19700 ms). Then, the helpful character exited the stage and the scene stayed for 2 seconds, depicting the protagonist laying down on top of the box (19700-24000 ms). In the antisocial scenario, the hindering character jumped on the box next to the protagonist and prevented the box from opening. The protagonist then jumped off the container and lay down beside it, appearing defeated and not achieving its goal, and the hindering character jumped off the box (13900-19700 ms). Then, the hindering character exited the stage and the scene stayed for 2 seconds, depicting the protagonist laying down beside the box (19700-24000 ms).

During each test trial, first, an attention getter was shown for 1000 ms, followed by a fixation cross with a duration that varied between 1200 and 1400 ms. Afterward, an image displaying the helper or hinderer was shown for 2000 ms.

At the end of each familiarization and test trial, an indefinitely long black screen was presented then the experimenter played the next trial once infants were attentive. The familiarization videos were presented in an alternating pattern, with the order of showing a helping or hindering video first being counterbalanced. Additionally, the placement of the helpful and hindering characters on the left or right side of the stage, as well as the color of the helper/hinderer puppets (orange/grey), were counterbalanced. Also, during test trials the order of helper and hinderer images was randomized.

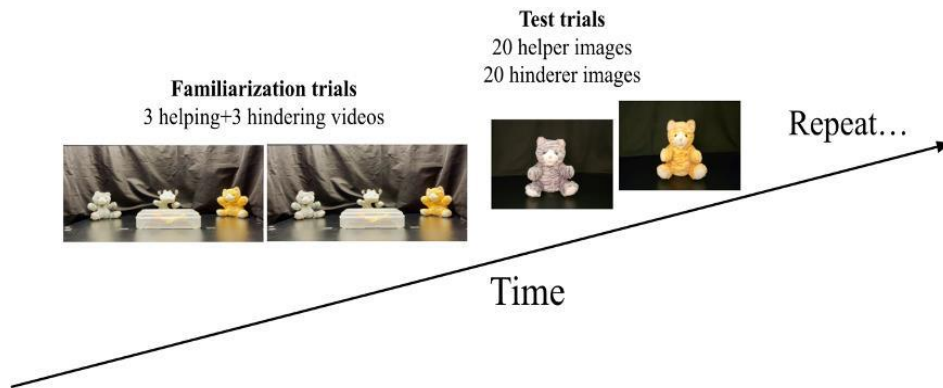


Figure 2. 1. Schematic diagram of the stimuli

Once infants completed one block of 6 familiarization and 40 test trials or became inattentive (i.e., bored of the still images), the next block of familiarization and test trials was presented. Infants were shown stimuli in this manner until they were no longer attentive and/or became fussy. Infants' behaviors were videotaped and coded offline after the study. 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 (Cowell & Decety, 2015; Tan & Hamlin, 2022), and have at least 10 helper and 10 hinderer artifact-free trials for the still images (Gredeback et al., 2015; Tan & Hamlin, 2022). On average, 2 blocks of trials were presented to the participants. The average number of helping and hindering videos was 5.31 and 5.33, respectively, and infants viewed an average of 24.69 helper and 23.83 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. Once the transfer was complete, the data then underwent offline filtering. First, an anti-aliasing filter was applied to the data to remove under-sampled frequencies. The data were also adjusted to account for event marker time offsets that may affect timing of the markers. 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, with a criterion of excluding channels with an absolute Z-score greater than 3.

To reduce other types of artifacts that make data unusable 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). Next, 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

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. The segments were baseline corrected using the mean amplitude of the 200 ms before the presentation of the stimulus to account for normal baseline brain activity. Trials were excluded if over 5 channels were outside the artifact threshold ($-200 \mu\text{V}$ to $200 \mu\text{V}$) or if infants were looking away from the screen (based on manual coding).

To calculate average N290 and P400 amplitude, signals were extracted from channels in the occipitotemporal area, including the temporoparietal junction, from 150-300 ms and 250-400 ms following stimulus onset, respectively (left hemisphere: E31, E33, right hemisphere: E40, E38; Figure 2.2). 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). ERPs and time windows of interest were based on previous studies (Gredeback et al., 2015; Tan & Hamlin, 2022).

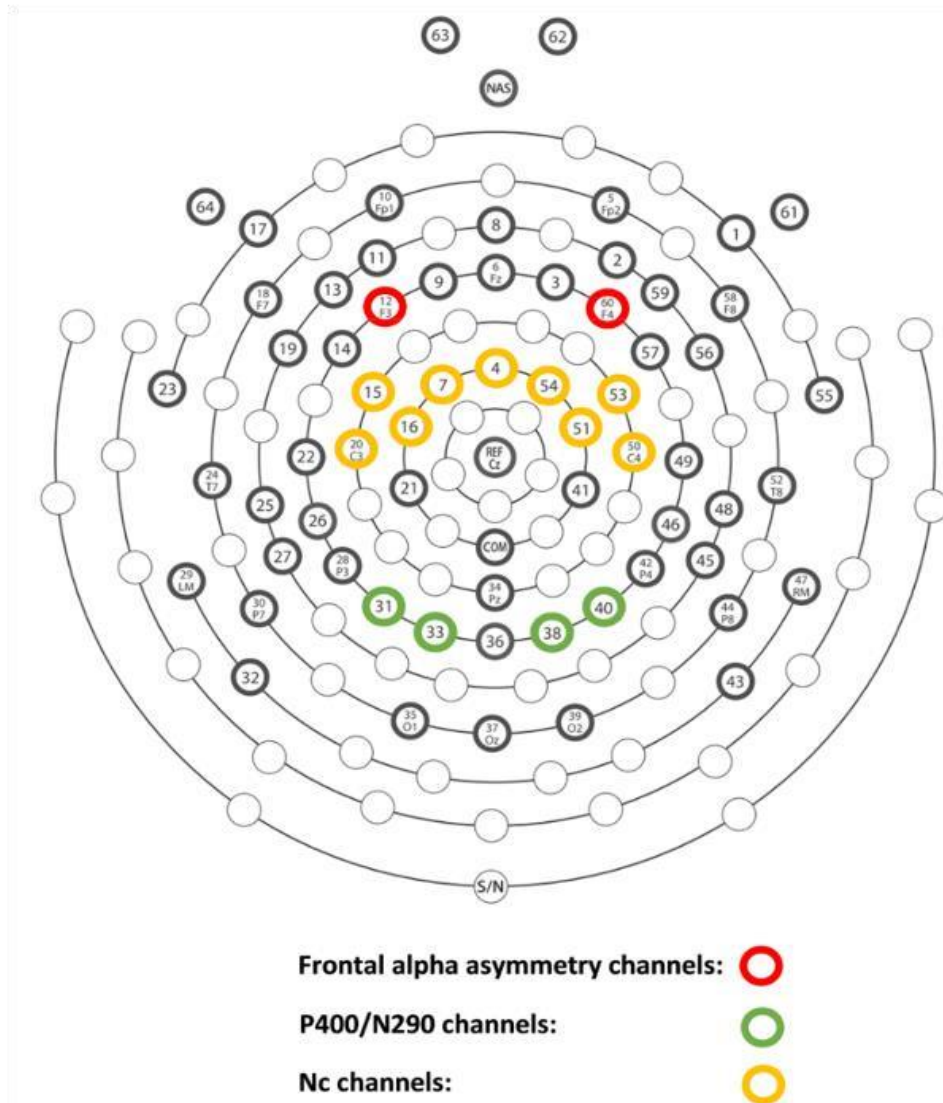


Figure 2.2. Channels used for frontal alpha asymmetry, P400/N290, and Nc analyses

Familiarization Trials (Frontal Alpha Asymmetry Analysis)

Following the pre-processing stage, the EEG data from the familiarization trials was divided into segments ranging from 2000 ms before the video's start to 24,000 ms after the onset. Subsequently, trials with less than 70% looking time and trials containing excessive movement artifacts were rejected through visual inspection.

The videos were separated into 4 phases (see Figure 2.3), including 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), Post-phase (end of helping/hindering action to 2 seconds after the helper/hinderer's exit from stage, 19,700-24,000 ms).



Baseline (-2000-0 ms)



Pre-phase (0-13900 ms)



During-phase (13900-19700 ms)



Post-phase (19700-24000 ms)

Figure 2.3. Phases of familiarization trials (the helping condition)

The data were divided into 500 ms windows with 50% overlap. A threshold of $-200 \mu\text{V}$ to $200 \mu\text{V}$ 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). On average, there were 543.17 and 549.94 usable segments for the helping and hindering videos, respectively.

Finally, to compare the frontal alpha asymmetries, the average power density for right (F4/E60) and left (F3/E12) frontal channels (Figure 3.3) in the 5-8 Hz frequency band were transformed by a natural log. Then, the difference scores were calculated ($\ln[F4]-\ln[F3]$). Baseline correction is not necessary for frontal alpha asymmetry scores because these scores already reflect the relative spectral powers between the hemispheres (Hwang et al., 2020). The calculation approach, frequency band and channels were selected based on Tan and Hamlin (2022) and Cowell & Decety (2015) and preregistered on OSF.

Results

Prior to both ERP and frontal alpha asymmetry analysis, outliers were removed using the `rstatix` (version 0.7.2) `identify_outliers` function. Outliers were classified as values 3 interquartile ranges (IQRs) above the 75th percentile or below the 25th percentile. One outlier was removed for the P400, N290, and Nc analyses. 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 Shapiro-Wilk's tests.

ERPs Analysis

To examine whether infants exhibited distinct responses to helping and hindering still images from the test trials based on social processes, we conducted separate 2 (condition: helping or hindering) x 2 (hemisphere: right or left) two-way ANOVAs for both the P400 and N290 ERP components.

For the P400 component (indexing social processing), the two-way ANOVA showed a marginal main effect for condition, $F(1, 34) = 3.89$, $p = .057$, $\eta^2 = .103$ (Figure 3.1). No significant effect of hemisphere, $F(1, 34) = 54.23$, $p = .523$, $\eta^2 = .012$, and no interaction between the variables was found, $F(1, 34) = 15.02$, $p = .272$, $\eta^2 = .035$. This pattern replicates results from Tan and Hamlin (2022) using a distinct helping and hindering scenario.

Given that the data displayed more variability in the hinderer than the helper condition (Figure 3.1), we conducted a non-parametric Wilcoxon Matched Pairs Test on condition (aggregated over hemisphere) to complement our parametric analysis. The results showed a significantly greater P400 amplitude in the hinderer than helper condition $W(35) = 182$, $p = 0.0287$, consistent with Tan and Hamlin (2022).

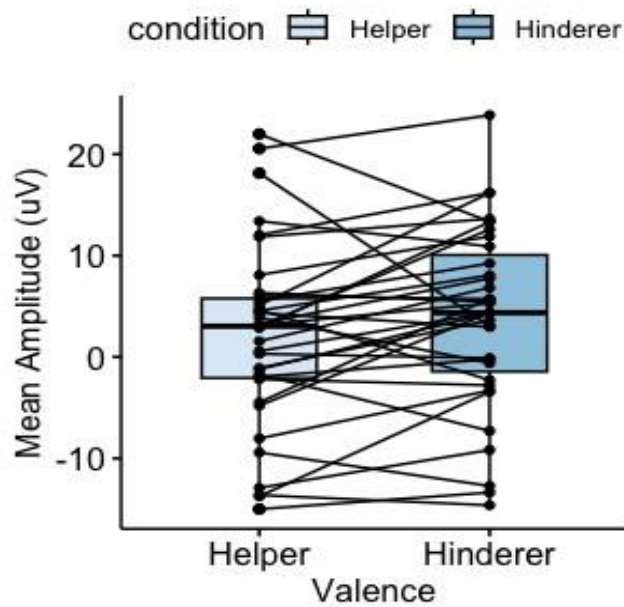


Figure 3. 1. P400 amplitude in helper and hinderer condition

Finally, as past studies have shown that the P400 component is elicited laterally, with greater amplitude in the right than left hemisphere (e.g., Galazka et al., 2016; for review, see Nelson et al., 2006), we ran a post-hoc test to examine whether there was a difference between helper and hinderer condition in the right hemisphere. The results showed that the P400 amplitude was statistically significantly higher in the hinderer than helper condition over the right hemisphere channels, $t(34) = -2.38$, $p = 0.023$, $M = 2.664329$, 95% CI [-4.94 0.39]. No significant effect was observed over the left hemisphere, $p > .05$ (Figure 3.2). These results are also consistent with findings from Tan & Hamlin (2022).

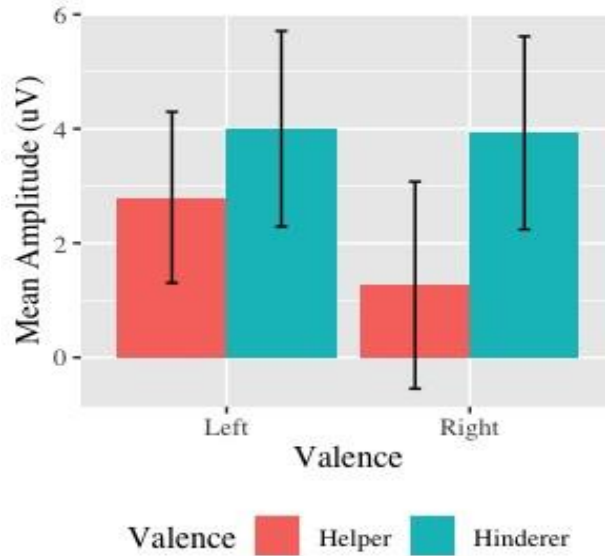


Figure 3. 2. P400 amplitude in helper and hinderer conditions over the right and left hemispheres

For the N290 component (indexing social processing), the two-way ANOVA showed no significant main effect of condition, $F(1, 34) = 1.23, p = .276, \eta^2 = .035$ or hemisphere, $F(1, 34) = 1.49, p = .230, \eta^2 = .042$. N290, and no interaction between the variables, $F(1, 34) = 1.23, p = .276, \eta^2 = .035$. A complementary non-parametric Wilcoxon Matched Pairs Test also found no significant difference between conditions, $W(34) = 250, p = 0.295$. However, a post-hoc test on condition over the right hemisphere showed a significant effect of condition $W(35) = 159, p = 0.0498$ with higher mean amplitudes for the hindering compared to the helping still images (Figure 3.3), indicating that infants are processing helping and hindering still images differently in the right hemisphere, consistent with Tan & Hamlin's (2022) results that found marginal effect in the N290 component.

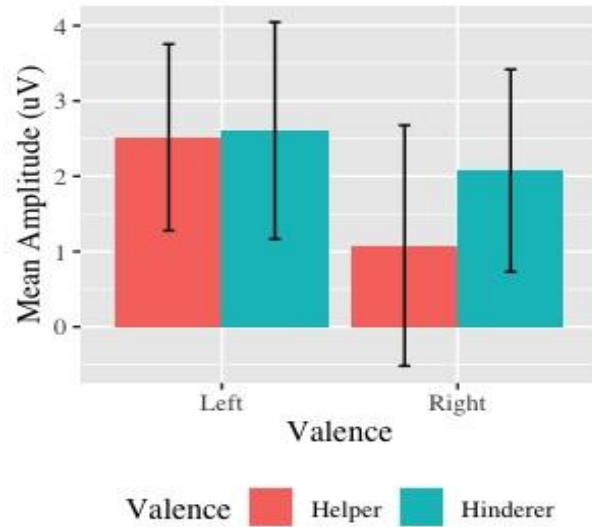


Figure 3. 3. N290 amplitude in helper and hinderer conditions over the right and left hemispheres

To address potential low-level perceptual explanations for the differential P400/N290 responses between the helping and hindering conditions, we conducted a paired-sample t-test on the Nc component (indexing domain-general attentional processing), $t(34) = -0.79$, $p = 0.437$, $M = -0.60$, 95% CI [-2.15 0.95] (Figure 3.4). 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)

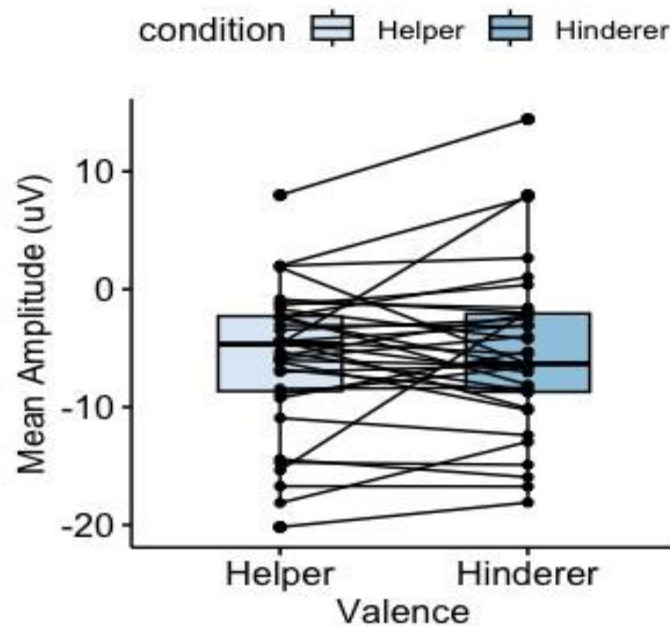


Figure 3. 4. Nc amplitude in the helper and hinderer conditions

Frontal Alpha Asymmetry Analysis

We conducted a two-way ANOVA to investigate infants' frontal alpha asymmetry scores from the familiarization trials. Within-subjects factors were condition (helping or hindering) and phase (Baseline, Pre-phase, During phase, and Post-phase). The results showed no significant interaction effect, $F(1, 35) = .84, p = .447, \eta_p^2 = .023$. 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) over the phases. To evaluate this effect, we used either paired samples t-tests or non-parametric Wilcoxon-tests, depending on the Shapiro-Wilk normality test. The results showed that the frontal alpha asymmetry was not significant in any phases ($p > .05$) (Figure 3.5). This result was inconsistent with Tan and Hamlin (2022)'s findings with 6-month-

olds' differential frontal alpha asymmetry responses, but was consistent with 12-month-old's absence of differential frontal alpha asymmetry results.

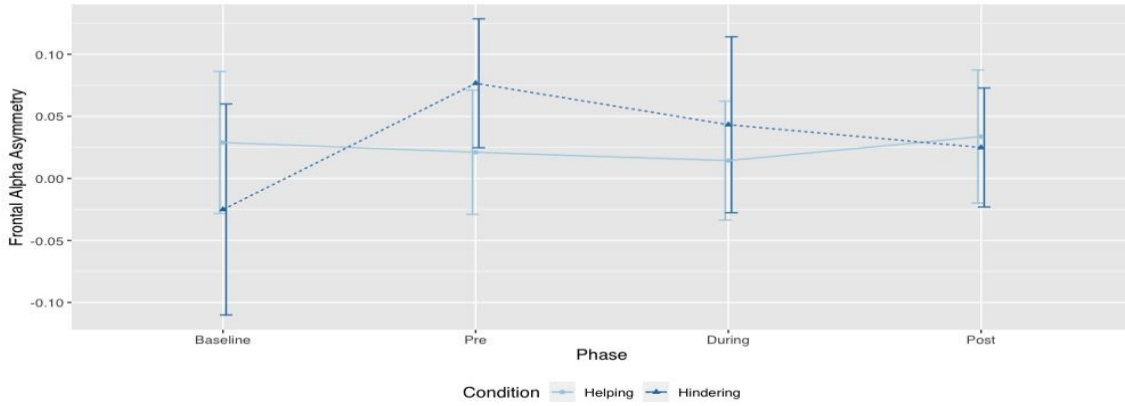


Figure 3. 5. Frontal Alpha Asymmetry (Right Hemisphere – Left Hemisphere)

Discussion

The present study aimed to understand the neural mechanisms underlying infants' prosocial preferences. Exploring the generality of past findings using the hill paradigm, here we examined 6-month-old infants' ERP components related to social processing (indexed by P400, N290) and domain-general, attentional processing (indexed by Nc) in the box paradigm. Replicating past work, we found that the P400 component, but not the Nc, was elicited differentially in response to still images of helping and hindering characters. Considering that the P400 component is associated with social processing (e.g., Csibra et al., 2008; de Haan et al., 2003), the observed differences in amplitudes between the helping and hindering characters implies that infants are processing these characters differently using social processes, consistent with the hypothesis that infants have a social understanding of prosocial and antisocial scenarios that generalizes beyond a single helping/hindering display.

Our results did not show a significant difference in the N290 component following viewing still images of helpers versus hinderers. That said, hinderer images did elicit significantly higher N290 amplitude than did helper images over the right hemisphere. This finding is, overall, consistent with Tan and Hamlin's (2022) findings of a marginal difference of N290 component between the helping and hindering conditions. Given that, similarly to the P400, the N290 component is implicated in social processing (e.g., Csibra et al., 2008, Nelson et al., 2006), the difference in mean amplitudes between hinderer and helper images suggests that infants' ability to distinguish helpers from hinderers involves social mechanisms.

We found a lateral effect in both the P400 and N290 responses to the hindering and helping still images. The higher amplitudes of the P400 over the right hemisphere are consistent with Tan and Hamlin's (2022) findings and other past studies on infants' perception of goal-

directed actions (e.g., higher for congruent pointing than incongruent pointing, Gredaback et al., 2010). Additionally, higher amplitudes of the N290 in the right hemisphere channels have been observed in face processing studies through source localization in infants (Johnson et al., 2005). Moreover, neuroimaging studies have shown higher activation of the right hemisphere during face processing in both adults (e.g., Lee et al, 2020) and infants (e.g., Grossman et al, 2000).

Notably, in both the current study and in Tan and Hamlin (2022), the effect of character valence on the N290 component is weaker than the valence effect on the P400 component. Based on past infant neurophysiological studies, one possible explanation for the weaker N290 effect might be that although the N290 likely reflects social processing in general, it may be more specialised for face processing in particular (e.g., Conte et al., 2020; Guy et al., 2022), and as such may not be as sensitive to social valence as is the P400. Further, using source-localization, Johnson et al., (2005) found that 3- and 12-month-old infants showed greater activity in the fusiform gyrus, right STS and surrounding temporal lobe in response to upright than inverted faces. Moreover, Guy and colleagues' (2016) results revealed greater N290 amplitudes in response to human faces than toys, which were derived from the fusiform gyrus, parahippocampal gyrus, and temporal pole. More recent studies also found that fusiform gyrus as the main generators of the N290 in response to facial expressions (Conte et al., 2020; Xie et al., 2019). In contrast, studies that have investigated the P400 in response to face stimuli have reported inconsistent results (de Haan et al., 2002, Guy et al., 2016). Taken together, these findings suggest that the P400 and N290 components might be specialized in processing distinct types of social information, with the N290 primarily involved in identifying human faces and the P400 dedicated to recognizing goal-directed and interactive social actions.

Why is there stronger responding in social components to hinderers than to helpers? A potential explanation for the higher P400 and N290 amplitudes for hinderers comes from behavioral work that suggests that infants are more sensitive to negative social agents and outcomes compared to positive ones. For example, 3-month-old infants viewing the hill paradigm have been shown to distinguish helpers from hinderers, and hinderers from neutral others, but not helpers from neutral others (Hamlin et al., 2010). Further, 6-month-olds who viewed inanimate “claws” help and hinder an agent in the box scenario subsequently attributed more agency to the hinderer claw than the helper claw, as measured by infants’ likelihood to attribute persistent object goals to the claws (Hamlin & Baron, 2014). These results, combined with previous ERP studies that have consistently reported larger P400 amplitudes in infants when they observe other agentive acts (e.g., goal-directed actions compared to non-goal-directed actions; congruent actions compared to incongruent actions; Bakker et al., 2015, 2016; Gredebäck et al., 2010), suggest that infants are more likely to show larger P400 responses when process stimuli that elicit a stronger sense of agency or goal attribution. Specifically, that infants showed larger P400 responses to hinderers supports arguments that negative actions and agents are more likely to trigger agency perception and other forms of mentalizing in infancy than are positive or neutral ones, perhaps due to the critical nature of identifying and avoiding harmful agents in one’s environment (for further discussion see Woo et al., 2023). Future studies should examine infants’ P400 responses to prosocial/antisocial characters in other contexts and across development in order to further clarify the direction of this effect.

But what does the existence of the P400 effect tell us about the nature of the social mechanisms underlying infants’ sociomoral evaluations? Specifically, does an increased P400 component in response to social events reflect social perceptual processes via lower-level non-

mentalistic representations of social inputs, or more sophisticated social processing based on higher-level mentalistic understanding of interactions? One way to answer this question may be to look at source-localization work, which has shown that the P400 component is associated with activity in the superior temporal sulcus (STS; Dalrymple et al., 2011; Itier & Taylor, 2004; Puce et al., 2003). So far, there have been two main views explaining the underlying mechanisms of STS activation. Some argue that low-level social processing is responsible for social processing in the STS, without the need for mentalizing. Supporting this idea, a recent study by Pitcher and Ungerleider (2021) investigated human and non-human primates and argued for the existence of a specific visual pathway on the lateral brain surface for processing social inputs. This visual pathway, projecting from the early visual cortex through motion-selective areas into the STS, selectively responds to moving faces and bodies, which could then facilitate interpreting others' actions.

In contrast, others propose that STS activation itself reflects higher-level social processing, such as mentalizing and intention-reading (e.g., Deen et al, 2015). Supporting this idea, previous adult studies found that the STS differentiates between interactive versus noninteractive social acts, such as two individuals facing toward versus away from each other (Walberin et al., 2017, 2018). Further, Isik and colleagues (2020) investigated the speed of social interaction perception in adults using magnetoencephalography (MEG). They presented participants with snapshots of visually matched real-world scenes depicting two people either interacting or acting independently. Results showed that the MEG data could spontaneously decode presence versus absence of a social interaction as well as the types of social interactions (e.g., mutual gaze vs joint attention). However, subjects' representations did not come online until quite late, at 300 ms and 500 ms after image onset, respectively. They argued that since

past studies have shown that age, gender, identity (Dobs et al., 2018), and even emotion expressions (Dima et al., 2018) are all decodable extremely quickly (around 100 ms) after the image onset, the relatively slow processing of social interactions suggest that it likely relies on iterative, top-down computations rather than feedforward visual processing. Finally, Isik and colleagues (2017) identified a sub-region in the prSTS that is sensitive to the valence of social interactions, specifically distinguishing helping from hindering (note that the direction of this effect was not specified in the manuscript), consistent with the infant data presented here and in past work (e.g., Gredeback et al., 2015; Tan & Hamlin, 2022).

Our data cannot speak about the mechanisms underlying STS activation or whether social interactions can be processed based on mentalizing versus non-mentalizing processing of relevant visual features, mainly due to the absence of source localization. However, it is worth noting that perceptual differences between our helpers and hinderers were socially meaningless without integrating information from the prior 6 videos of familiarization trials (lasting 144 seconds). That is, instead of directly presenting social differences in the test stimuli, as seen in some previous studies (e.g., Pitcher & Ungerleider, 2021), in order to show any differential response to the test images here infants must have drawn upon the social interactive information stored in memory (see also Gredeback et al., 2015). Given this, it seems unlikely that infants distinguished helpers from hinderers solely based on social perceptual processing. Future work should systematically investigate the extent to which specific brain areas are specialised in early responses to the sociomoral world, as well as how distinct regions of the infant brain integrate social information by utilizing techniques with higher spatial resolution.

Unlike the P400 and N290, there was no differential response in the Nc component indexing attentional processing. This pattern is consistent with several previous investigations

into infants' responses to the sociomoral world (Gredebäck et al, 2015; Tan & Hamlin, 2022), and suggests that infants are not differentiating between the helping and hindering characters based solely on perceptual features of helping and hindering events or other low-level attentional mechanisms. This provides further support for the conclusion that infants distinguish between helpers and hinderers based on their social differences, as opposed to (for instance) physical differences that may exist between the scenes. That said, the Nc component has been associated with processing of helping versus hindering interactions in toddlers, using a distinct prosocial and antisocial interaction (Cowell & Decety, 2015). One important note is that this study measured the Nc component during three-picture sequences of prosocial and antisocial interactions, rather than afterward when toddlers viewed still images of the characters; the Nc may have been responding to the very real perceptual differences that existed between prosocial and antisocial events. Indeed, Cowell and Decety's (2015) prosocial and antisocial actions were sometimes quite perceptually distinct. For example, in one of their scenarios, the helpful character moves toward the protagonist and gives it a hat, whereas the hindering character instead throws a ball at the character's head. These perceptual differences between the interactions may have led to the differential response in the Nc.

The second goal of the current study was to examine whether motivational processes are involved when infants process prosocial and antisocial interactions, by measuring frontal alpha asymmetry during prosocial versus antisocial events. Results showed no significant differences in frontal alpha asymmetry based on event type. This result was inconsistent with Tan and Hamlin (2022)'s findings with 6-month-olds, who observed greater right alpha power (indexing approach motivation) during the helping versus hindering videos, and with Cowell and Decety (2015)'s findings with 12-24-month-olds, who observed greater left alpha power

(indexing avoidance motivation) in hindering than helping videos. However, it aligned with the absence of differential frontal alpha asymmetry observed in 12-month-olds in Tan & Hamlin's (2022) study. That is, past work on this question has been inconsistent, which might suggest that the frontal alpha asymmetry response is not particularly robust. In addition, given that we used a new set of helping/hindering interactions, one possible interpretation of these findings is that the increased approach motivation observed during the helping videos compared to the hindering videos, as seen in studies with the hill paradigm, may not be robust enough to be generalized to other prosocial/antisocial events or be consistently observed across different age groups.

Adding to this inconsistency, although previous work on frontal alpha asymmetry have shown that relative right frontal alpha power is linked to greater approach motivation, this effect exists for both positive (e.g., happiness) and negative (e.g., anger) emotions (for review, see De Haan et al., 2003). This leaves open the possibility to observe even higher right frontal alpha power during a hindering event, if infants experience an approach-oriented response, for instance becoming angry when viewing a hindering event (see also Tan & Hamlin (2023), that found infants frown more during hindering than helping videos). Future studies with younger and older age groups and employing different scenarios could help clarify and shed light on this discrepancy.

Several limitations for the current work need to be noted. One major constraint, common to all infant EEG studies, is the high criteria set for the number of stimuli an infant must view without excessive movement artifacts to remain in the sample. This resulted in a relatively high attrition rate of 50%. We aimed for a high standard to ensure a robust signal for effect detection;

however, it does restrict our sample to infants who could maintain attention for a relatively extended period.

Another important note to consider in interpreting the results of this study is the potential complexity of the box scenario stimuli for younger infants like the 6-month-olds tested here. Although previous behavioral studies using the box paradigm have shown that infants as young as 5 months of age successfully evaluated the helping and hindering characters, it has taken relatively more trials for infants to be habituated to the box show (Hamlin and Wynn, 2011), and the effect size is relatively lower than for other prosocial/ antisocial scenarios, particularly the ball paradigm (for review, see Margoni & Surian, 2018).

Supporting this idea, Woo & Spelke's (2022) study revealed, the protagonist's goal in the box paradigm (i.e., opening the box versus opening the box to retrieve the toy) is relatively complex to grasp for younger infants, resulting in different interpretations by 8-month-old infants, who understand the action goal based on means-end understanding (i.e., Opening the box lid) compared to 15-month-old infants, who perceive the goal as opening the box to retrieve the toy (see also Sommerville & Woodward (2005) that showed this more generally). Indeed, although the current results showed that even 6-month-old infants distinguish the helpful and hindering characters using social processes, rather than low-level attentional processes, the results are relatively weaker than the past three EEG studies using the hill paradigm. Future studies with older infants with the same paradigm would be beneficial to examine the generalizability and robustness of the current results.

Another limitation pertains to sample demographics. The participants in our study mostly came from well-educated families, with 83.33% having at least one parent with a Bachelor's degree. Additionally, the ethnic descent of our sample is relatively homogenous, with

38.88% being of European descent and 22.21% of East and South Asian descent. As a result, the generalizability of our findings may be limited due to the lack of representation from diverse socioeconomic and ethnic backgrounds.

In summary, the current study utilized the box show, a new helping and hindering interaction, to investigate whether infants' sociomoral evaluations are supported by social neural processes (rather than attentional ones) and whether approach/avoidance motivation plays a role in how 6-month-old infants process these interactions. The results are broadly consistent with previous studies on helping-hindering interactions (Gredebäck et al., 2015; Tan & Hamlin, 2022), indicating that infants apply similar social processing to sociomoral agents in various helping and hindering scenarios. However, we did not observe a significant effect for the involvement of approach/avoidance motivation. Overall, our findings contribute to the growing body of evidence suggesting that infants engage in genuinely sociomoral evaluation from an early age. Future work should explore sociomoral events in other domains (e.g., fairness, physical harm, etc.) in order to further explore the breadth and robustness of these effects.

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