Developmental Neurobiology

WILEY

RESEARCH ARTICLE OPEN ACCESS

The Intriguingly Social N400 of Preverbal Infants

Bálint Forgács[1,2] | Eugenio Parise[3] | Judit Gervain[4] | Nóra Berkes[1] | Adél Szigeti[1] | Belma Bumin Feride[1] | Ildikó Király[1,5]

[1]Department of Cognitive Psychology, Institute of Psychology, ELTE Eötvös Loránd University, Budapest, Hungary | [2]Department of Experimental and Neurocognitive Psychology, Freie Universität, Berlin, Germany | [3]CIMeC—Center for Mind/Brain Sciences, Università di Trento, Trento, Italy | [4]Dipartimento di Psicologia dello Sviluppo e della Socializzazione—DPSS, Università di Padova, Padua, Italy | [5]MTA-ELTE Social Minds Research Group, Institute of Psychology, ELTE Eötvös Loránd University, Budapest, Hungary

Correspondence: Bálint Forgács (forgacs.balint@ppk.elte.hu)

Received: 14 July 2025 | **Revised:** 27 February 2026 | **Accepted:** 7 March 2026

Keywords: language processing | mentalization | N400 | social cognition | Theory-of-Mind

ABSTRACT

Recent investigations have shown that the neural processing of linguistic content may interact with social cognition. Specifically, semantic processing, as reflected by the N400 event-related potential, appears to be sensitive to manipulations of Theory of Mind (ToM), the ability to attribute mental content to social partners. In this study, we labeled objects for 14-month-old infants either correctly or incorrectly (an N400 manipulation), ehiter in the presence or absence of an observer. We found that the N400 response was enhanced in the presence (relative to the absence) of the social partner, but only for the incongruent labels. ToM's role in language comprehension has long been proposed, but the outcome that ToM may impact not solely pragmatic but also semantic level computations—already at the developmental onset of the N400 response—may warrant a reevaluation of the functional organization of the language system. Although a large body of developmental research suggests that language may be a prerequisite for ToM, our findings raise the possibility that ToM may play a fundamental role in language acquisition. Linguistic content may be processed by a semantic system functioning mentalistically, recovering meaning as intended by communicative partners, which could hold the key to the rapid word learning of infants.

1 | Introduction

Many researchers have pointed out the importance of social interactions in language development (e.g., Bruner 1983; Vygotsky 1986). This view fits well with the Gricean tradition of communicational pragmatics that emphasizes the role of communicative intentions in the appropriate interpretation of language (Grice 1975; Sperber and Wilson 1986). Some consider the ability to attribute intentions, mental states, beliefs, and desires to social partners—i.e., mentalizing or having a Theory-of-Mind (ToM) (Leslie 1994; Premack and Woodruff 1978)—indispensable for human communication (Tomasello 2008) and language acquisition (Baldwin 1991, 1993; Bloom 2000; Macnamara 1972; Tomasello 2008). Others, argue, however, that ToM is optional for communication (Sperber and Wilson 2024) or remain deliberately agnostic about its role (Bohn and Frank 2019). Therefore, it remains an open question what role ToM may play in language processing and word learning.

Recent findings on the N400 event-related potential (ERP), linked to semantic processing (Kutas and Federmeier 2011), have challenged the traditional view that communicative-pragmatic inferences may take place only following an initial semantic decoding of language (Grice 1975; Reboul and Moeschler 1998; Sperber and Wilson 1986). The so-called "social N400" effect (Jouravlev et al. 2019; Rueschemeyer et al. 2015; Westley et al. 2017) suggests that social cognition may influence semantic processing. These studies employed a "joint comprehension" task in which participants read classical N400 sentences with unusual endings (e.g., "The boy had gills"). Participants were also made to listen to additional context sentences that should have eliminated the N400 by rendering the unusual endings plausible (Filik and Leuthold 2008; Nieuwland and Van Berkum 2006). When participants read the target sentences together with a confederate, who did not hear the context sentences, they still showed an N400. They thus produced an N400 "on behalf of" their confederate, in response to a semantic incongruency experienced not by themselves, but by another person. This effect was termed the "social N400." Note that, unlike a typical N400 response, the social N400 is not elicited by a semantic processing load, although it resembles an N400 in terms of scalp distribution and latency and is evoked by linguistic events.

The social N400 response appears to be sensitive not merely to general social cognition but to mentalistic manipulations proper, both in adults (Forgács et al. 2022) and infants (Forgács et al. 2019, 2020; Kampis et al. 2025). This effect was shown in studies that induced a false belief in an observer by replacing an object (e.g., a shoe) with another (e.g., a bunny), unbeknownst to the observer. Participants produced an N400 in response to labels that were congruent for them (i.e., bunny) but incongruent with the false belief of the observer. Thus, the N400 appears to be sensitive to the belief state of an interlocutor, not simply to social-communicative context or to the information asymmetry created in joint comprehension tasks. Traditionally, a false belief manipulation is assumed to trigger ToM or pragmatic mechanisms and should not affect the semantic system directly. Yet, our previous studies revealed a direct link between false belief manipulation and lexical lookup, suggesting that semantic processes may rely on mentalizing. The present experiment aims to further investigate the social N400 by breaking down linguistic communication into two elemental building blocks: semantic processing and the presence of a communicative partner.

There are two intriguing implications of the social N400 findings. The first concerns the mechanisms underlying the N400, and the possibility that it may function mentalistically; the second concerns how and when mentalization may contribute to the comprehension of linguistic meaning during semantic–pragmatic processing. Regarding the first question, a consensus is emerging that instead of semantic integration (Hagoort et al. 2009), the N400 indicates semantic memory retrieval effort (Brouwer et al. 2012; Kutas and Federmeier 2011; Urbach et al. 2020; Van Berkum 2009): It is always elicited but reduced when semantic expectancies are met. There is also broad agreement that semantic computations should not be influenced by pragmatic operations. Pragmatic processes may run in parallel with other interpretative mechanisms (Sperber and Wilson 1986), but a logical form of the utterance still needs to be computed, even if it is not considered semantic in nature, which then serves as an input to pragmatic inferences (Reboul and Moeschler 1998; Sperber and Wilson 2002). Although we are not firmly committed to such a theoretical distinction between pragmatics and semantics, the N400 has typically been described as reflecting semantic, rather than pragmatic, mechanisms (Brouwer 2026; Canal and Bambini 2023; Van Berkum 2009). Pragmatic ERPs have mainly been reported in the time window following the N400 (Canal and Bambini 2023; Chevallier et al. 2010; Noveck and Posada 2003; Politzer-Ahles et al. 2013). Even though there are a few reports that the N400 responds to pragmatic-like manipulations, on a closer look, they do not seem to counter the lexico-semantic explanation.

Van Berkum (2009) proposes that even if the N400 may sometimes seem to elude the lexical retrieval account, it is fundamentally a semantic ERP. Even in these special cases, the relevant contextual and pragmatic inferences could have been derived prior to target sentences. The N400 is sensitive to world knowledge, be it real (Hagoort et al. 2004) or fictional (Troyer and Kutas 2020; Troyer et al. 2020, 2022); to stereotypes of gender (White et al. 2009), age, and social status (Van Berkum et al. 2008); and even to personal values (Van Berkum et al. 2009). Importantly, the relevant pragmatic inferences could adjust semantic expectancies anticipatorily and beyond the word or sentence level, within a deep semantic-conceptual layer (Rabovsky et al. 2018; Rabovsky et al. 2024). However, Van Berkum's account still faces difficulties explaining why the N400 is sensitive to the valence of words (Holt et al. 2009), to accentuation (Li et al. 2008), or to hesitations (Corley et al. 2007), which do not seem to involve pragmatic–social–cognitive inferences either. It may be argued that all of them are some sort of contextual effects, but context, when used so broadly, is not specific to the N400. Instead, contextual integration modulates the P600 (Brouwer et al. 2012), just like implicatures (Noveck and Posada 2003; Politzer-Ahles et al. 2013), contrastive accent (Chevallier et al. 2010), or irony (Regel et al. 2011), marked by prosody (Regel and Gunter 2017). When communicative intentions can be identified for speech acts (requesting vs. naming), such a (pragmatic) context impacts processing already around 120–150 ms (Egorova et al. 2013; Tomasello et al. 2019). Even if one subscribes to the idea that the N400 responds to hesitation, accentuation, or valence as "context," the joint comprehension N400 (Rueschemeyer et al. 2015) still does not fit the picture. It requires a contextual *subtraction*, not an addition: The confederate receives less information than the participant, yet participants produce an N400 as if they did not have the information either. In other words, the predictive state of the semantic system would need to be reset instead of enriched by (social) context. Using the notion of context in such a broad sense washes away the distinction between semantics, pragmatics, and the semantic–pragmatic interface (Moeschler 2018; Schlenker 2016).

Importantly, the false belief social N400 paradigm (Forgács et al. 2019, 2022) posed no semantic processing demands, because objects were always labeled correctly from the participants' perspective. Consequently, there was no need for semantic memory retrieval effort. Moreover, it required no pragmatic inferences either—contextual, logical, or social—because tracking the belief state of a social partner is not an inference but an attribution. Since the manipulation concerned false beliefs exclusively, the results raise the possibility that the N400 may reflect ToM mechanisms.

Even though the joint comprehension experiments manipulated the amount of information participants needed to evaluate when attending to the comprehension of a confederate, and neither of these studies provided direct evidence for mentalization, they still offered it as an explanation in some form. Rueschemeyer et al. (2015) suggest that the social N400 reflects a "mirroring mechanism": Keeping track of another person's interpretation is similar to keeping track of our own interpretation. Jouravlev et al. (2019)

explain the effect as indicative of "emphatic confusion" and talk about perspective taking and representing and modeling other minds. However, because these studies are built on inverting the contextual attenuation of the N400 (Filik and Leuthold 2008; Nieuwland and Van Berkum 2006), the joint comprehension findings are exposed to non-mentalistic explanations, based on some kind of pragmatic and/or semantic–contextual predictive mechanisms.

In contrast, we argue that the above diverse N400 effects that do not lend themselves easily to a classical semantic memory account could gain a unified explanation if one assumes that the semantic system producing the N400 functions mentalistically (Forgács 2024). Semantic predictions may be generated based on informative intentions (Sperber and Wilson 1986) attributed to the speaker. The false-belief social N400 paradigm (Forgács et al. 2019) required neither semantic processing nor pragmatic inferences—only mentalization. These considerations provide a mentalistic explanation not only for the false-belief N400 but also for other, seemingly paradoxical N400 results, including the social-presence N400 (Forgács et al. 2022).

This leads to the second implication: Whether mentalization is a necessary part of language comprehension and acquisition. While Neo-Griceans remain "deliberately agnostic" about ToM (Bohn and Frank 2019), Post-Griceans argue that mentalization is merely an optional input to pragmatic computations (Mazzarella and Noveck 2021; Sperber and Wilson 2024), which are carried out by a dedicated pragmatic module (Pléh 2000; Sperber and Wilson 2002), separate from ToM (Bosco et al. 2018). Despite the large body of research into communicative intentions (Bloom 1997, 2000; Brooks and Meltzoff 2008, 2013; Brown-Schmidt et al. 2008; Clark and Brennan 1991; Csibra 2010; Macnamara 1972; Martin et al. 2012; Nadig and Sedivy 2002; Nilsen and Graham 2009; Sabbagh and Baldwin 2001; Tomasello 2008; Vouloumanos et al. 2014), it remains mostly underspecified when, how, and which specific beliefs may be attributed, if at all, during the processing of informative intentions or meaning as intended. The mentalistic social N400 experiments made some steps in this direction when they showed that the semantic system responds to particular (false) belief states, that is, the mental content of social partners.

Similarly, the field of cognitive development has also been grappling with the relationship between ToM and language. As ToM seemed to come online only around 4 years of age (Perner et al. 1987), ToM researchers suggested that language development may be a prerequisite for ToM (de Villiers 2000; de Villiers and de Villiers 2000; de Villiers and Pyers 2002; Harris et al. 2005; Helming et al. 2014; Milligan et al. 2007; Olson 1988; Rubio-Fernandez 2021; Ruffman et al. 2003). However, this line of research equated ToM with what explicit, verbal tasks measure. Implicit paradigms have found that already 6–8-month-old infants exhibit ToM (Kampis et al. 2015; Kovács et al. 2010; Scott and Baillargeon 2017; Southgate and Vernetti 2014). Despite attempts to explain these findings away (Apperly and Butterfill 2009; Heyes 2014; Tomasello 2018) and concerns about their replicability (Baillargeon et al. 2018; Dörrenberg et al. 2018), an accumulating body of evidence cannot be accounted for without assuming adult-like, meta-representational ToM in infancy (Kampis and Kovács 2022; Király et al. 2018, 2023; Kovács et al. 2021). The false belief social N400 studies (Forgács et al. 2019, 2020) fit this pattern by revealing that preverbal 14-month-old infants can attribute semantic representations that are in a semantic-propositional computational format suitable for adult-like ToM.

The present study aims to explore the mentalistic manipulations engaging the semantic system of 14-month-olds (Forgács et al. 2019, 2020). In adults, the N400 appears to be sensitive to two layers of mentalization: a spontaneous tracking of comprehension, elicited by social presence, and a more strategic tracking of miscomprehension due to false beliefs, which is apparent only upon explicit instructions (Forgács et al. 2022). Our question here is whether the mere presence of another person has an impact on semantic processing at 14 months of age, at the developmental onset of the N400 (Friedrich and Friederici 2005, 2008). We labeled objects correctly or incorrectly for 14-month-olds in the presence or absence of an adult. Note that our manipulation did not require increased semantic processing or additional pragmatic inferences between the two conditions of social presence versus absence. If the social-presence N400 in adults (Forgács et al. 2022) is due to extensive conversational routine in social-communicative interactions, we may not observe it in 14-month-olds, who have more limited experience in linguistic-communicative exchanges compared to adults. If social presence primarily activates social-cognitive systems that process pragmatics and/or mentalization, which then co-activate the semantic system, we may expect to observe both an N400 and additional ERPs indicative of these mechanisms. However, if solely an enhanced N400 response is apparent, accompanied by no additional ERPs, it may suggest that the semantic system recovers meaning through mentalistic attributions even when no false beliefs necessitate ToM processes.

2 | Materials and Methods

Infants were seated on their caregiver's laps in a dimly lit room. They were presented with short videos in which familiar objects were placed on a table and named, while an adult in the video either appeared seated on the other side of the table or was absent. We ran two experiments to limit the number of conditions for each infant to two. In Experiment 1, objects were labeled correctly in the presence or absence of an observer. In Experiment 2, objects were labeled incorrectly in the presence or absence of an observer (Figure 1). We treated these two experiments separately because of repetition attenuation effects on ERPs: The N400 response is reduced by repeated exposure to linguistic incongruency. Consequently, comparing an experiment employing only incongruent labels to another with only congruent labels cannot be expected to yield an N400 difference. In fact, such block designs are typically not suitable for, and are avoided in, ERP research. The reason we paired the social presence versus alone conditions within experiments is because this contrast is the comparison of interest of our study, whereas the infant N400 response is a relatively well-established and replicated effect in 14-month-olds (Forgács et al. 2019; Friedrich and Friederici 2005, 2008; Kampis et al. 2024) and even in 9-month-olds (Junge et al. 2012; Parise and Csibra 2012).

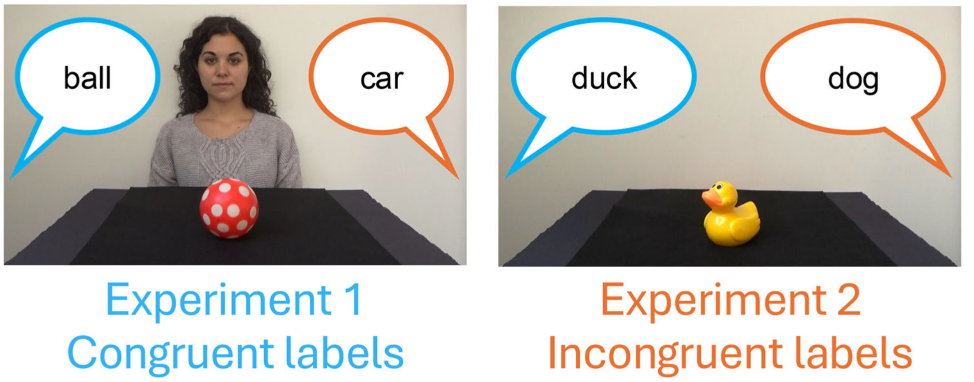

FIGURE 1 | Experimental paradigms of the two experiments. Objects were labelled either in the presence or absence of an observer: Always correctly in Experiment 1 and always incorrectly in Experiment 2.

2.1 | Participants

We tested 14-month-old infants (+/− 2 weeks), with 20 infants participating in Experiment 1 and 20 in Experiment 2. All of them were full-term, typically developing, Hungarian monolingual babies (hearing any other languages <15% of the time, according to parental report). Upon arrival, caregiver(s) were informed about the experiment and their written informed consent was obtained. In Experiment 1, infants' ages ranged between 412 and 437 days, M (SD) = 421.3 (7.85) days, eight of them were female. In Experiment 2, ages ranged between 410 and 440 days, M (SD) = 428.4 (8.83) days, with 15 females. Additionally, 36 babies did not complete the study due to fussiness or crying and 10 infants were excluded due to technical error (e.g., computer malfunction, camera disconnected). A further 86 babies were excluded because they did not produce at least 10 artifact-free trials per condition (Stahl et al. 2010); another 16 babies had 10 good trials per condition, but their grand average ERPs were too noisy (did not show ERP indicators of acoustic processing); and two infants were excluded, because they fell outside the age range. All rejection were done in batch before statistical analyses were conducted. Taken together, we reached a 21% inclusion rate, which is comparable to studies testing 14-month-olds in similar paradigms (Forgács et al. 2019, 2020). It is important to note that exclusion was not based on any cognitive or perceptual abilities relevant to our research question (e.g., working memory, language comprehension, mentalization, or social cognition) but was due to fussiness and most of all, noise driven by eye-movement patterns that were entirely natural and normal. The fact that there were two eye-catching stimuli on the screen simultaneously, a person looking in the camera and an object to be labeled, gave rise to frequent eye-movements during labeling events, which led to a large number of excluded trials. Although we believe infants were not excluded in any systematic way that could have interfered with the goals of our study, we cannot rule out the possibility that some cognitive developmental factors may have played a role.

2.2 | Stimuli

We recorded 15 short videos showing a table in front of a white wall, with one of 15 objects placed in the middle of the table. Another 15 video clips featured a single female experimenter seated in front of the wall and behind the exact same table, on which the same objects were placed, one at a time. Each video started with an object already present, the experimenter noticing it by briefly looking at it for about ~2 s and then looking neutrally into the camera. After about ~2 s an audio label was played back, which lasted for about 300–500 ms. The scene remained visible on the screen for another 3–4 s. Each video lasted about 7–8 s. We used 15 objects known to our target age group (Forgács et al. 2020; Parise and Csibra 2012): apple, ball, banana, book, bunny, car, cat, cup, dog, duck, phone, shoe, sock, spoon, and teddy (toys and real-world objects). Object labels were the corresponding Hungarian words, audio recorded separately and played back either congruently or incongruently with the visible object. In addition, we recorded auditory attention getter exclamations (e.g., Look what I am showing! and How interesting!), and we also used various short attention getter videos, all of which could be played back on demand during the experimental session.

2.3 | Experimental Procedures

Upon arriving to the lab with their family or caregiver, infants were invited to a warm-up playtime to familiarize them with the lab and the experimenters. After putting the EEG cap on, infants were seated on their caregiver's laps in a dimly lit, sound attenuated and electrically shielded EEG lab room in front of a computer screen, where videos were presented. Caregivers were requested not to look at the screen to avoid involuntary reactions to events and limit their interactions with their child to soothing if necessary and were provided with headphones playing soft music in order to avoid influencing infants' reactions.

Infants were randomly assigned to participate either in Experiment 1 or Experiment 2. The video stimuli were played back by the experimenter trial by trial, who also controlled the EEG system and followed events from a neighboring room via a video feed of infants' faces. Attention getter videos and audios were played back on demand and short breaks were introduced in case the infant became fussy or inattentive. In Experiment 1, all labels were correct; in Experiment 2, all labels were incorrect. The within-experiment manipulation was the presence or absence of an adult in the video during object labeling events, whereas the between-experiment manipulation was label congruity. The experiments lasted as long as infants maintained their attention, or up to a maximum of 150 trials, corresponding to about 30 min of EEG recording. On average, infants saw 45 trials in the social absence and 52 in the social presence condition in Experiment 1, and 47 in the social absence and 51 trials in the social presence condition in Experiment 2. Individual pseudorandom stimulus lists were generated for each participant using Python 3.6 (Python Software Foundation, Beaverton, Oregon, USA), which ensured that no more than two consecutive trials belonged to the same condition (social presence vs. absence), that no object or label appeared repeatedly in four consecutive trials, and that in Experiment 2, where labels were all incorrect, no potential priming may occur: Incongruent labels were selected so as not to be related to the visible object—for example, not referring to category members ("duck" not labeling a bunny), resembling it neither visually ("ball" not labeling an apple), nor phonologically (the word *kanál* "spoon," not labeling *kacsa* "duck," which share the same first phoneme in Hungarian). After the EEG recording session, infants received a small gift toy to thank them for their participation, and caregivers were informed about all the details of the experiment and given the opportunity to ask questions. The experimental session typically lasted about 1 h.

2.4 | EEG Recording and Data Processing

We obtained a continuous EEG signal with EGI Magstim's saline-based EEG system, suitable for infants, using Net Station 4.5.1 software. We recorded raw EEG data with 128-channel Hydrocel Geodesic Sensor Nets (HCGSN) at 500 Hz sampling rate. For data processing, we used an offline bandpass filter between 0.3 and 30 Hz, segmented data 200 ms before and 1200 ms after word audio playback onset, and ran Net Station's default automatic artifact detection algorithms for blinks, eye-movements, and bad channels. The default settings were the following: A channel was marked bad if the difference between the minimum and maximum amplitude value within a segment exceeded the threshold of 200 mV, using a moving window of 80 ms; a trial was marked for blinking if the difference between the minimum and maximum values over eye-channels exceeded 140 mV, using a moving window of 80 ms; a trial was marked for eye-movements if the difference between the minimum and maximum values over eye-channels exceeded 55 mV, using a moving window of 80 ms. We then visually checked the EEG data and compared it with the video recording for any additional disturbances not picked up or misidentified automatically. After artifact rejection, on average, 18/45 and 16/52 trials per infant were included in Experiment 1 and 21/47 and 16/51 trials remained in Experiment 2 in the absence and in the presence conditions, respectively. Next, bad channels were replaced by interpolation, segments were averaged by condition, baseline corrected to 200 ms pre-stimulus baseline, and re-referenced to the average reference. Individual ERP averages were further checked for basic characteristics of acoustic ERPs: (1) a flat, zero average baseline, ensuring that the two ERP conditions started from the same amplitude (~0 μV) at stimulus onset; (2) a slow, slight positive deflection frontally and a slow, slight negative deflection parietally (given that we used an average re-referencing); (3) ERPs to the two conditions showing a comparable overall morphology. For statistical analyses we extracted amplitude values over a parietal Region-of-Interest (ROI) consisting of 13 electrodes (62, 65, 66, 67, 70, 71, 72, 75, 76, 77, 83, 84, and 90) between 400 and 600 ms, typical for infant N400, and a frontal ROI of 13 electrodes (3, 4, 5, 9, 10, 11, 12, 15, 16, 18, 19, 22, and 23) between 300 and 500 ms (based on Forgács et al. 2020). All raw EEG data are available at osf.io/2pmh9.

3 | Results

The ERP results are shown in Figure 2. First, we compared individually averaged ERP data recorded in the infant N400 time window (400–600 ms), over the parietal ROI in response to the social absence and the social presence conditions using a paired *t*-test. In Experiment 1 (congruent labels) we found no significant difference between the two conditions, $t(19) = 1.22$, $p = 0.24$, $d = 0.27$. We did find, however, a greater negativity in the social presence relative to the social absence condition in Experiment 2 (incongruent labels), $t(19) = 3.64$, $p = 0.002$, $d = 0.82$ (achieved power = 93%).

In addition, we tested whether a frontal ERP response showed up as in our previous false belief social N400 experiments (Forgács et al. 2019, 2020). We found no statistically significant differences in the 300–500 ms time window for either Experiment 1, $t(19) = 1.10$, $p = 0.286$, $d = 0.25$, or Experiment 2, $t(19) = -1.58$, $p = 0.130$, $d = -0.35$. Exploratorily, we also tested whether there is a frontal effect between 400 and 600 ms, as visual inspection hinted at one, but found no statistical evidence (*p*s > 0.37).

Although the samples in the two experiments were not balanced between females and males, excluding the last five males to arrive to the lab from Experiment 1 or the last five females to arrive from Experiment 2 did not change the pattern of results. Taken together, we found an N400-like response to social presence, but only when labeling was incongruent (Experiment 2), whereas there was no indication of any frontal response.

4 | Discussion

In this study, we set out to investigate the role mentalization may play in language comprehension in preverbal infants. We created an experimental paradigm to study the elemental components of linguistic interactions: Whether the mere presence of another person influences semantic processing. We presented and labeled objects for 14-month-olds in the presence or absence of an adult observer. Word labels elicited an enhanced ERP response when another person was present, exactly in the time window (400–600 ms) and at a scalp distribution (centro-parietal, slightly skewed to the right) typical for an infant N400, an established indicator of semantic processing (Kutas and Federmeier 2011). This response appears to be employed strategically, not automatically, as it was present only when object labels were incorrect, not when they were correct. These findings shed new light on how semantic processing, pragmatic mechanisms, and ToM come together during language comprehension in social contexts. Infants' semantic system appeared to be sensitive to mentalistic manipulations right at the developmental emergence of the N400, a neural indicator of adult-like semantic comprehension. Importantly, the social presence manipulation did not require additional semantic processing, and yet infants' semantic system

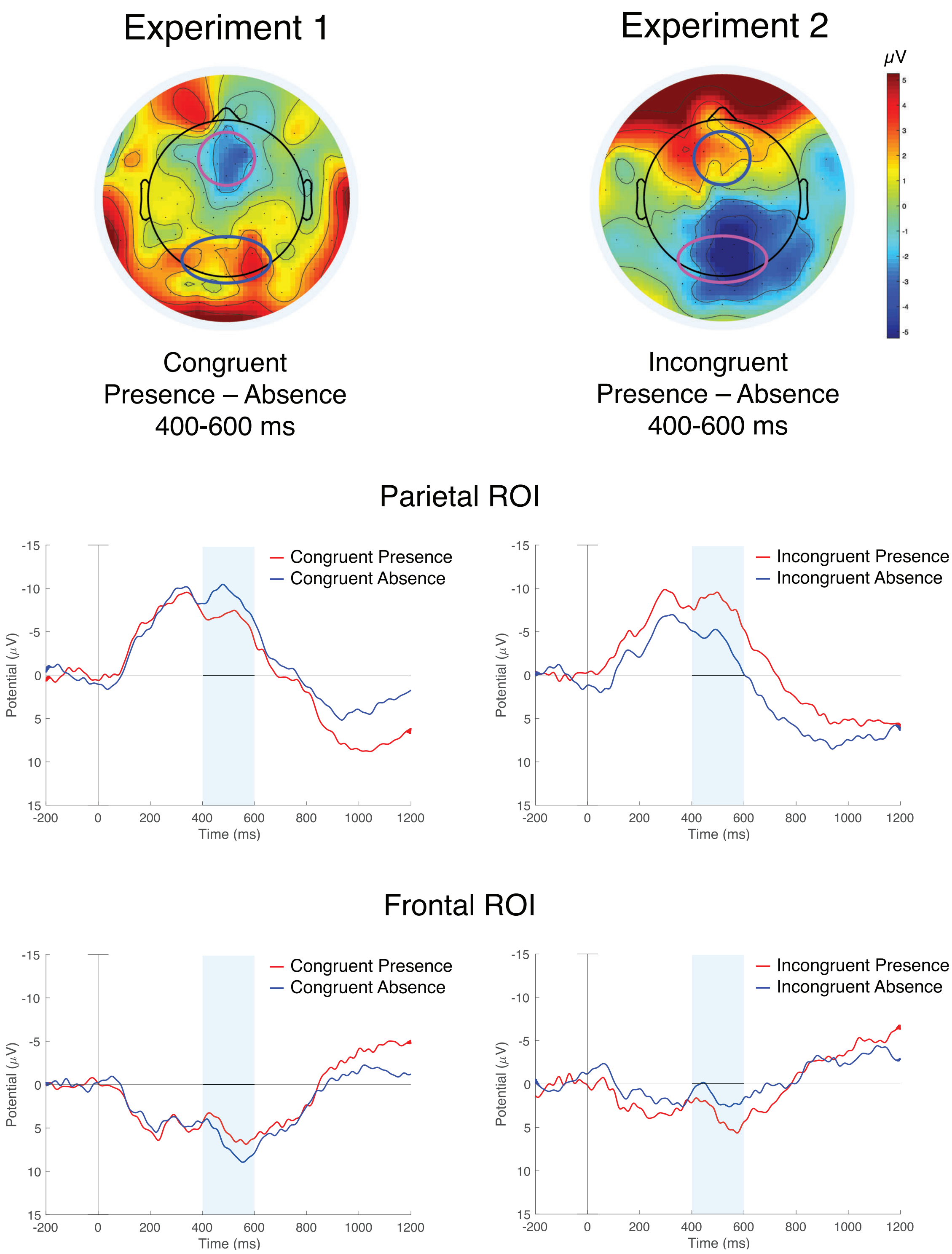

FIGURE 2 | Social presence N400 effect. Upper panel shows topographical difference maps of within-subject conditions separately for Experiments 1 and 2 in the 400–600 ms time window. Cold colors indicate more negative amplitudes, warm colors more positive ones. Colored rings mark the frontal and parietal ROIs over which statistical analyses were carried out. Lower panel shows ERPs averaged over the two ROIs. Negative is plotted upwards. Light blue shadings indicate the 400–600 ms time window of the infant N400. The topographic distribution of the social presence N400 effect in the incongruent labeling experiment (upper left) noticeably resembles the distribution of the typical N400 response: centro-parietal, slightly skewed to the right. No other significant effects were observed. ROI, Region-of-Interest.

activated when comprehension perspectives with a social partner might have diverged.

It may be argued that the enhanced N400 response in the presence of another person in Experiment 2 is not indicating mentalistic processes, just some sort of general social cognitive mechanism, for example, social facilitation. This explanation can, however, be excluded, as because if social facilitation drove the effect in Experiment 2, it should have shown up in Experiment 1 as well. It is also rather challenging to explain the above results via pragmatics, in the sense of extra-linguistic inferential mechanisms (Noveck, 2018; Noveck and Sperber 2004; Sperber and Wilson 1986) and/or of social cognition (Bohn and Frank 2019), devoid of mentalization. First, ERPs linked to social-pragmatic mechanisms, like the P600, show up after, not before semantic analysis in the N400 time window (Canal and Bambini 2023; Van Berkum 2009). It is true that pragmatic factors may set up the communicative context, for example, for speech acts, which may lead to early pragmatic effects (Egorova et al. 2013; Tomasello et al. 2019). However, our simple experimental paradigm does not seem to warrant productive pragmatic inferences to derive because there is no additional social and/or contextual information that could be utilized for them: There is no other object or person on the scene, and so on. Even if social presence is treated as such a pragmatic factor, it is not clear what pragmatic inference may be derived from it? We would argue that social presence in and of itself does not warrant productive pragmatic inferences. Second, these unspecified pragmatic mechanisms would need to subtract rather than enrich information if one assumes that the N400 is linked to some kind of expectancy. The N400 is thought to be elicited by default and reduced if expectancies are met, but it is unclear how social presence induced pragmatic inferences should reduce expectancies? Pragmatic inferences do not seem to provide a strong explanation for our data.

On a closer look, the current social presence paradigm posed neither lexico-semantic nor pragmatic-inferential processing demands. Under a mentalistic account the (less reduced) N400 in Experiment 2 could indicate a heightened activation of a broader set of elements in semantic memory because of the attribution of miscomprehension to the other person, over and above the miscomprehension by the self. Such enhanced semantic activation could boost preparation for potentially ensuing communicative interactions in infants and adults alike (Forgács et al. 2022). This is important from a communicative perspective, because interlocutors need to agree on label-referent pairs if they wish to sustain communication with each other.

Such tracking does not seem to be necessary for infants when labels correctly match their referents, in contrast to adults (Forgács et al. 2022), because we did not observe a social-presence N400 in Experiment 1. This outcome suggests that infants' semantic system does not engage in mentalistic processes when they assume that they fully share the observer's experience of comprehension. Similar to the findings of Király et al. (2018), if there is no reason to create an extra representation for the other, a computationally efficient ToM system may ration neural resources. Instead of attributing true beliefs, it may suffice to sustain a single, socially normative belief that may be assumed to be shared (Király et al. 2018, 2023). When the label is incongruent, however, perspectives may diverge, and a shared belief would not suffice to track the communicative situation. A linguistic incongruity may create a greater communicative ambiguity; thus, additional representations and a broader set of semantic elements for possible alternative continuations may need to be activated. The ability to entertain the possibility that another listener may have a different interpretation for contextually predictable words as well may emerge only with conversational experience in linguistic interactions. Future studies are necessary to test this idea.

The appearance of the social presence N400 in 14-month-olds, right at the developmental onset of the N400 (Friedrich and Friederici 2005, 2008), is quite remarkable. The fact that infants' semantic system produces both a social-presence N400 and a false-belief social N400 (Forgács et al. 2020, 2019) suggests that when the semantic processor comes fully online during the course of development, it is just as sensitive to multiple levels of mentalistic manipulations as in adults.

The finding that the social presence effect manifested as an N400 with no accompanying frontal ERP effect may have important implications for the neural organization of the semantic system. Note that we found a frontal effect in our prior false belief N400 studies, when an observer had a false belief at the time of labeling events (Forgács et al. 2019, 2020), which was not the case in the present experiments. On a classical account, the language network (Binder et al. 1997; Fedorenko et al. 2010) has been suggested to be independent of other cognitive systems, including arithmetic, music, working memory, and cognitive control (Fedorenko and Varley 2016), as well as ToM (Fedorenko et al. 2024; Shain et al. 2023). Some neural clusters of social cognition have been found to be correlated with language related terms but it could have been due to the linguistic expressions of mentalization concepts (Schurz et al. 2020). A recent study reported that the ToM and language networks were correlated more strongly within themselves than with one another (Paunov et al. 2019): They seem functionally distinct yet synchronized—at least when probed with classical tasks. However, prior to their analysis, Paunov and colleagues removed regions overlapping between the two networks (7%–8% in area), arguing that their goal was to measure internetwork synchronization. In doing so, they may have removed not only regions that could have revealed whether the networks are not separate, but also parts that may play a key role in the functioning of either of them. Moreover, in a hierarchical cluster analysis, the left angular gyrus, which they assigned to the language network, still grouped with the ToM network. This region is not only contralateral to the right temporo-parietal junction, a key area of mentalization (Mar 2011; Schurz et al. 2014, 2020), but also at Wernicke's area, a neural generator of the N400 (Federmeier and Laszlo 2009; Lau et al. 2008; Van Petten and Luka 2006). It may not be by chance that precisely the angular gyrus stood out in a later study as well, which also implied the right hemisphere homologues of language areas in ToM (Shain et al. 2023). The right hemisphere is thought to play a crucial role in situating language in its social context (Van Lancker Sidtis 2006)—in other words, in the communicative intentions of speakers. More importantly, just because classical ToM tasks do not engage a narrowly defined language network (Fedorenko et al. 2024), the semantic system may still function mentalistically.

Importantly, it is not clear how the two networks may be "synchronized" (Paunov et al. 2019) for the social presence N400 effect to emerge. A linguistic input would need to trigger the ToM system, which should either produce a neural signature identical with the N400 in timing and distribution, or immediately trigger back the semantic system for an N400 to emerge. Given that the N400 is sensitive to a host of semantic factors, such as word frequency or associations (Laszlo and Federmeier 2011), and is thought to be non-post-lexical (Deacon et al. 2000)—that is, predictive yet bottom-up—the N400 being controlled by the ToM system does not seem highly plasuible.

A perhaps more plausible, even if unusual, explanation of our findings is that the semantic system may function in a mentalistic manner (Forgács 2024). Meaning could be computed as intended and/or as comprehended by communicative partners, based on the mental content attributed to them. The semantic system may even have originated and specialized from, and still function as, one of many ToM systems. It could take into consideration both the linguistic characteristics of the input and the beliefs of communicative partners.

In conclusion, our finding that 14-month-olds produce an enhanced N400 response to incongruent word labels in the presence of another person raises the possibility that the semantic system may be mentalistic in nature. The importance of grasping attention (Baldwin 1991; Baldwin and Markman 1989) or intentions (Bloom 1997, 2000; Macnamara 1972) in word learning has been emphasized before. However, our results hint at the attribution not of attention but of beliefs, and not for referent resolution but as mental content per se. These findings may foster a reevaluation of the relation between semantics, pragmatics, and ToM in word learning.

Author Contributions

Bálint Forgács: conception and design, acquisition, analysis and interpretation of data, drafting and revising the manuscript. **Eugenio Parise**: analysis and interpretation of data, revising the manuscript. **Judit Gervain**: analysis and interpretation of data, revising the manuscript. **Nóra Berkes**: acquisition and analysis of data. **Adél Szigeti**: acquisition and analysis of data. **Belma Bumin Feride**: analysis of data. **Ildikó Király**: conception and design, interpretation of data, revising the manuscript.

Acknowledgments

We would like to thank the committed work of Lili Hanna Glöckler and Nicole Peer with data gathering and Lívia Priyanka Elek the help with creating the stimuli.

Funding

This research received partial financial support from the Post-Covid Programme of the Hungarian Academy of Sciences (MTA Post-Covid/2021) to Ildikó Király; the ECOS Sud action nr. C20S02, the ERC Consolidator Grant 773202 "BabyRhythm," the ANR's French Investissements d'Avenir—Labex EFL Program under Grant [ANR-10-LABX-0083], the Italian Ministry for Universities and Research FARE grant nr. R204MPRHKE and PRIN grant nr. 2022WX3FM5, as well as the "SYNPHONIA" project (nr. CLP: PNRR-MAD 2022-12376739; CUP: C63C22001320007) funded by the European Union Next Generation EU NRRP M6C2, Investment 2.1, "Enhancement and strengthening of biomedical research in the NHS" to Judit Gervain.

Ethics Statement

The study was approved by the Research Ethics Committee of the Faculty of Education and Psychology at ELTE Eötvös Loránd University, Budapest, Hungary.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All raw EEG data are available at osf.io/2pmh9.

References

Apperly, I. A., and S. A. Butterfill. 2009. "Do Humans Have Two Systems to Track Beliefs and Belief-Like States?" *Psychological Review* 116, no. 4: 953–970. https://doi.org/10.1037/a0016923.

Baillargeon, R., D. Buttelmann, and V. Southgate. 2018. "Invited Commentary: Interpreting Failed Replications of Early False-Belief Findings: Methodological and Theoretical Considerations." *Cognitive Development* 46, no. May: 112–124. https://doi.org/10.1016/j.cogdev.2018.06.001.

Baldwin, D. A. 1991. "Infants' Contribution to the Achievement of Joint Reference." *Child Development* 62, no. 5: 875–890. https://doi.org/10.2307/1131140.

Baldwin, D. A. 1993. "Early Referential Understanding: Infants' Ability to Recognize Referential Acts for What They Are." *Developmental Psychology* 29, no. 5: 832–843. https://doi.org/10.1037/0012-1649.29.5.832.

Baldwin, D. A., and E. M. Markman. 1989. "Establishing Word-Object Relations: A First Step." *Child Development* 60, no. 2: 381–398. https://doi.org/10.2307/1130984.

Binder, J. R., J. A. Frost, T. A. Hammeke, R. W. Cox, S. M. Rao, and T. Prieto. 1997. "Human Brain Language Areas Identified by Functional Magnetic Resonance Imaging." *Journal of Neuroscience* 17, no. 1: 353–362. https://doi.org/10.1523/jneurosci.17-01-00353.1997.

Bloom, P. 1997. "Intentionality and Word Learning." *Trends in Cognitive Sciences* 1, no. 1: 9–12. https://doi.org/10.1016/S1364-6613(97)01006-1.

Bloom, P. 2000. *How Children Learn the Meanings of Words*. MIT Press. https://doi.org/10.7551/mitpress/3577.001.0001.

Bohn, M., and M. C. Frank. 2019. "The Pervasive Role of Pragmatics in Early Language." *Annual Review of Developmental Psychology* 1, no. 1: 223–249. https://doi.org/10.1146/annurev-devpsych-121318-085037.

Bosco, F. M., M. Tirassa, and I. Gabbatore. 2018. "Why Pragmatics and Theory of Mind Do Not (Completely) Overlap." *Frontiers in Psychology* 9, no. 1453: 1–7. https://doi.org/10.3389/fpsyg.2018.01453.

Brooks, R., and A. N. Meltzoff. 2008. "Infant Gaze Following and Pointing Predict Accelerated Vocabulary Growth Through Two Years of Age: A Longitudinal, Growth Curve Modeling Study." *Journal of Child Language* 35, no. 1: 207–220. https://doi.org/10.1017/S0305000907008 29X.

Brooks, R., and A. N. Meltzoff. 2013. "Gaze Following: A Mechanism for Building Social Connections Between Infants and Adults." In *Mechanisms of Social Connection: From Brain to Group*. American Psychological Association. https://doi.org/10.1037/14250-010.

Brouwer, H. 2026. "Mapping Meaning in the Brain's Language." *Cortex; A Journal Devoted to the Study of the Nervous System and Behavior* 194: 12–21. https://doi.org/10.1016/j.cortex.2025.10.012.

Brouwer, H., H. Fitz, and J. Hoeks. 2012. "Getting Real About Semantic Illusions: Rethinking the Functional Role of the P600 in Language Comprehension." *Brain Research* 1446: 127–143. https://doi.org/10.1016/j.brainres.2012.01.055.

Brown-Schmidt, S., C. Gunlogson, and M. K. Tanenhaus. 2008. "Addressees Distinguish Shared From Private Information When Interpreting Questions During Interactive Conversation." *Cognition* 107, no. 3: 1122–1134. https://doi.org/10.1016/j.cognition.2007.11.005.

Bruner, J. S. 1983. *Child's Talk: Learning to Use Language*. Oxford University Press.

Canal, P., and V. Bambini. 2023. "Pragmatics Electrified." In *Language Electrified*, edited by M. Grimaldi, E. Brattico, and Y. Shtyrov, 583–612. Humana Press. https://doi.org/10.1007/978-1-0716-3263-5_18.

Chevallier, C., M. Bonnefond, J. B. Van Der Henst, and I. A. Noveck. 2010. "Using ERPs to Capture Inferential Processes Guided by Prosodic Cues." *Italian Journal of Linguistics* 22, no. 1: 125–152.

Clark, H. H., and S. E. Brennan. 1991. "Grounding in Communication." In *Perspectives on Socially Shared Cognition*, edited by L. B. Resnick, J. M. Levine, and S. D. Teasley, 127–149. American Psychological Association. https://doi.org/10.1037/10096-006.

Corley, M., L. J. MacGregor, and D. I. Donaldson. 2007. "It's the Way That You, er, Say It: Hesitations in Speech Affect Language Comprehension." *Cognition* 105, no. 3: 658–668. https://doi.org/10.1016/j.cognition.2006.10.010.

Csibra, G. 2010. "Recognizing Communicative Intentions in Infancy." *Mind & Language* 25, no. 2: 141–168. https://doi.org/10.1111/j.1468-0017.2009.01384.x.

Deacon, D., S. Hewitt, C.-M. Yang, and M. Nagata. 2000. "Event-Related Potential Indices of Semantic Priming Using Masked and Unmasked Words: Evidence That the N400 Does Not Reflect a Post-Lexical Process." *Cognitive Brain Research* 9, no. 2: 137–146. https://doi.org/10.1016/S0926-6410(99)00050-6.

de Villiers, J. G. 2000. "Language and Theory of Mind: What Are the Developmental Relationships?" In *Understanding Other Minds: Perspectives From Developmental Cognitive Neuroscience*, 2nd ed. 83–123. Smith College.

de Villiers, J. G., and P. de Villiers. 2000. "Linguistic Determinism and the Understanding of False Beliefs." In *Children's Reasoning and the Mind*, edited by P. Mitchell and K. Riggs, 890–890. Psychology Press.

de Villiers, J. G., and J. E. Pyers. 2002. "Complements to Cognition: A Longitudinal Study of the Relationship Between Complex Synthax and False-Belief-Understanding." *Cognitive Development* 17, no. 1: 1037–1060. https://doi.org/10.1016/S0885-2014(02)00073-4.

Dörrenberg, S., H. Rakoczy, and U. Liszkowski. 2018. "How (Not) to Measure Infant Theory of Mind: Testing the Replicability and Validity of Four Non-Verbal Measures." *Cognitive Development* 46, no. February: 12–30. https://doi.org/10.1016/j.cogdev.2018.01.001.

Egorova, N., Y. Shtyrov, and F. Pulvermüller. 2013. "Early and Parallel Processing of Pragmatic and Semantic Information in Speech Acts: Neurophysiological Evidence." *Frontiers in Neuroengineering* 7, no. (March): 86. https://doi.org/10.3389/fnhum.2013.00086.

Federmeier, K. D., and S. Laszlo. 2009. "Time for Meaning: Electrophysiology Provides Insights Into the Dynamics of Representation and Processing in Semantic Memory." In *Psychology of Learning and Motivation—Advances in Research and Theory*, edited by D. H. Ross, 1–44. Elsevier. https://doi.org/10.1016/S0079-7421(09)51001-8.

Fedorenko, E., P. J. Hsieh, A. Nieto-Castañón, S. Whitfield-Gabrieli, and N. Kanwisher. 2010. "New Method for fMRI Investigations of Language: Defining ROIs Functionally in Individual Subjects." *Journal of Neurophysiology* 104, no. 2: 1177–1194. https://doi.org/10.1152/jn.00032.2010.

Fedorenko, E., A. A. Ivanova, and T. I. Regev. 2024. "The Language Network as a Natural Kind Within the Broader Landscape of the Human Brain." *Nature Reviews Neuroscience* 25, no. 5: 289–312. https://doi.org/10.1038/s41583-024-00802-4.

Fedorenko, E., and R. Varley. 2016. "Language and Thought Are Not the Same Thing: Evidence From Neuroimaging and Neurological Patients." *Annals of the New York Academy of Sciences* 1369, no. 1: 132–153. https://doi.org/10.1111/nyas.13046.

Filik, R., and H. Leuthold. 2008. "Processing Local Pragmatic Anomalies in Fictional Contexts: Evidence From the N400." *Psychophysiology* 45, no. 4: 554–558. https://doi.org/10.1111/j.1469-8986.2008.00656.x.

Forgács, B. 2024. "Meaning as Mentalization." *Frontiers in Human Neuroscience* 18: 1384116. https://doi.org/10.3389/fnhum.2024.1384116.

Forgács, B., J. Gervain, E. Parise, et al. 2020. "Electrophysiological Investigation of Infants' Understanding of Understanding." *Developmental Cognitive Neuroscience* 43: 100783. https://doi.org/10.1016/j.dcn.2020.100783.

Forgács, B., J. Gervain, E. Parise, et al. 2022. "Semantic Systems Are Mentalistically Activated for and by Social Partners." *Scientific Reports* 12, no. 1: 4866. https://doi.org/10.1038/s41598-022-08306-w.

Forgács, B., E. Parise, G. Csibra, G. Gergely, L. Jacquey, and J. Gervain. 2019. "Fourteen-Month-Old Infants Track the Language Comprehension of Communicative Partners." *Developmental Science* 22, no. 2: 12751. https://doi.org/10.1111/desc.12751.

Friedrich, M., and A. D. Friederici. 2005. "Lexical Priming and Semantic Integration Reflected in the Event-Related Potential of 14-Month-Olds." *Neuroreport* 16, no. 6: 653–656. https://doi.org/10.1097/00001756-200504250-00028.

Friedrich, M., and A. D. Friederici. 2008. "Neurophysiological Correlates of Online Word Learning in 14-Month-Old Infants." *Neuroreport* 19, no. 18: 1757–1761. https://doi.org/10.1097/WNR.0b013e328318f014.

Grice, H. P. 1975. "Logic and Conversation." In *Speech Acts*, edited by P. Cole and J. L. Morgan, 41–58. Academic Press. https://doi.org/10.1163/9789004368811_003.

Hagoort, P., G. Baggio, and R. M. Willems. 2009. "Semantic Unification." In *The Cognitive Neurosciences*, edited by M. S. Gazzaniga, 61–69. MIT Press. https://doi.org/10.7551/mitpress/8029.003.0072.

Hagoort, P., L. Hald, M. Bastiaansen, and K. M. Petersson. 2004. "Integration of Word Meaning and World Knowledge in Language Comprehension." *Science* 304, no. 5669: 438–441. https://doi.org/10.1126/science.1095455.

Harris, P. L., M. De Rosnay, and F. Pons. 2005. "Language and Children's Understanding of Mental States." *Current Directions in Psychological Science* 14, no. 2: 69–73. https://doi.org/10.1111/j.0963-7214.2005.00337.x.

Helming, K. A., B. Strickland, and P. Jacob. 2014. "Making Sense of Early False-Belief Understanding." *Trends in Cognitive Sciences* 18, no. 4: 167–170. https://doi.org/10.1016/j.tics.2014.01.005.

Heyes, C. 2014. "Submentalizing: I Am Not Really Reading Your Mind." *Perspectives on Psychological Science* 9, no. 2: 131–143. https://doi.org/10.1177/1745691613518076.

Holt, D. J., S. K. Lynn, and G. R. Kuperberg. 2009. "Neurophysiological Correlates of Comprehending Emotional Meaning in Context." *Journal of Cognitive Neuroscience* 21, no. 11: 2245–2262. https://doi.org/10.1162/jocn.2008.21151.

Jouravlev, O., R. Schwartz, D. Ayyash, Z. Mineroff, E. Gibson, and E. Fedorenko. 2019. "Tracking Colisteners' Knowledge States During Language Comprehension." *Psychological Science* 30, no. 1: 3–19. https://doi.org/10.1177/0956797618807674.

Junge, C., A. Cutler, and P. Hagoort. 2012. "Electrophysiological Evidence of Early Word Learning." *Neuropsychologia* 50, no. 14: 3702–3712. https://doi.org/10.1016/j.neuropsychologia.2012.10.012.

Kampis, D., and Á. M. Kovács. 2022. "Seeing the World From Others' Perspective: 14-Month-Olds Show Altercentric Modulation Effects by Others' Beliefs." *Open Mind* 5: 189–207. https://doi.org/10.1162/opmi_a_00050.

Kampis, D., D. Askitis, E. Poulsen, E. Parise, and V. Southgate. 2024. "14-month-old Infants Detect a Semantic Mismatch when Occluded Objects are Mislabeled." *Infancy* 29, no. 4: 510–524. https://doi.org/10.1111/infa.12597.

Kampis, D., D. Askitis, and V. Southgate. 2025. "Altercentric Bias in Preverbal Infants' Encoding of Object Kind." *Cognition* 257: 106074. https://doi.org/10.1016/j.cognition.2025.106074.

Kampis, D., E. Parise, G. Csibra, and Á. M. Kovács. 2015. "Neural Signatures for Sustaining Object Representations Attributed to Others in Preverbal Human Infants." *Proceedings of the Royal Society B: Biological Sciences* 282, no. 1819: 20151683. https://doi.org/10.1098/rspb.2015.1683.

Király, I., K. Oláh, G. Csibra, and Á. M. Kovács. 2018. "Retrospective Attribution of False Beliefs in 3-Year-Old Children." *Proceedings of the National Academy of Sciences* 115, no. 45: 11477–11482. https://doi.org/10.1073/pnas.1803505115.

Király, I., K. Oláh, and Á. M. Kovács. 2023. "Can 18-Month-Olds Revise Attributed Beliefs?" *Open Mind* 7: 435–444. https://doi.org/10.1162/opmi_a_00087.

Kovács, Á. M., E. Téglás, and G. Csibra. 2021. "Can Infants Adopt Underspecified Contents Into Attributed Beliefs? Representational Prerequisites of Theory of Mind." *Cognition* 213: 104640. https://doi.org/10.1016/j.cognition.2021.104640.

Kovács, Á. M., E. Téglás, and A. D. Endress. 2010. "The Social Sense: Susceptibility to Others' Beliefs in Human Infants and Adults." *Science* 330, no. 6012: 1830–1834. https://doi.org/10.1126/science.1190792.

Kutas, M., and K. D. Federmeier. 2011. "Thirty Years and Counting: Finding Meaning in the N400 Component of the Event-Related Brain Potential (ERP)." *Annual Review of Psychology* 62: 621–647. https://doi.org/10.1146/annurev.psych.093008.131123.

Laszlo, S., and K. D. Federmeier. 2011. "The N400 as a Snapshot of Interactive Processing: Evidence From Regression Analyses of Orthographic Neighbor and Lexical Associate Effects." *Psychophysiology* 48, no. 2: 176–186. https://doi.org/10.1111/j.1469-8986.2010.01058.x.

Lau, E. F., C. Phillips, and D. Poeppel. 2008. "A Cortical Network for Semantics: (de)Constructing the N400." *Nature Reviews Neuroscience* 9, no. 12: 920–933. https://doi.org/10.1038/nrn2532.

Leslie, A. M. 1994. "Pretending and Believing: Issues in the Theory of ToMM." *Cognition* 50, no. 1–3: 211–238. https://doi.org/10.1016/0010-0277(94)90029-9.

Li, X., P. Hagoort, and Y. Yang. 2008. "Event-Related Potential Evidence on the Influence of Accentuation in Spoken Discourse Comprehension in Chinese." *Journal of Cognitive Neuroscience* 20, no. 5: 906–915. https://doi.org/10.1162/jocn.2008.20512.

Macnamara, J. 1972. "Cognitive Basis of Language Learning in Infants." *Psychological Review* 79, no. 1: 1–13. https://doi.org/10.1037/h0031901.

Mar, R. A. 2011. "The Neural Bases of Social Cognition and Story Comprehension." *Annual Review of Psychology* 62: 103–134. https://doi.org/10.1146/annurev-psych-120709-145406.

Martin, A., K. H. Onishi, and A. Vouloumanos. 2012. "Understanding the Abstract Role of Speech in Communication at 12 Months." *Cognition* 123, no. 1: 50–60. https://doi.org/10.1016/j.cognition.2011.12.003.

Mazzarella, D., and I. Noveck. 2021. "Pragmatics and Mind Reading: The Puzzle of Autism (Response to Kissine)." *Language* 97, no. 3: e198–e210. https://doi.org/10.1353/LAN.2021.0037.

Milligan, K., J. W. Astington, and L. A. Dack. 2007. "Language and Theory of Mind: Meta-Analysis of the Relation Between Language Ability and False-Belief Understanding." *Child Development* 78, no. 2: 622–646. https://doi.org/10.1111/j.1467-8624.2007.01018.x.

Moeschler, J. 2018. *The Semantics-Pragmatics Interface: How It Works, Why We Need It and Where It Is*. Department of linguistics University of Geneva.

Nadig, A. S., and J. C. Sedivy. 2002. "Evidence of Perspective-Taking Constraints in Children's On-Line Reference Resolution." *Psychological Science* 13, no. 4: 329–336. https://doi.org/10.1111/j.0956-7976.2002.00460.x.

Nieuwland, M. S., and J. J. A. Van Berkum. 2006. "When Peanuts Fall in Love." *Journal of Cognitive Neuroscience* 18, no. 7: 1098–1111. https://doi.org/10.1162/jocn.2006.18.7.1098.

Nilsen, E. S., and S. A. Graham. 2009. "The Relations Between Children's Communicative Perspective-Taking and Executive Functioning." *Cognitive Psychology* 58, no. 2: 220–249. https://doi.org/10.1016/j.cogpsych.2008.07.002.

Noveck, I. A. and D. Sperber, eds. 2004. *Experimental Pragmatics*. Palgrave Macmillan UK. https://doi.org/10.1057/9780230524125.

Noveck, I. A., and A. Posada. 2003. "Characterizing the Time Course of an Implicature: An Evoked Potentials Study." *Brain and Language* 85, no. 2: 203–210. https://doi.org/10.1016/S0093-934X(03)00053-1.

Noveck, I. (2018). Experimental Pragmatics. https://doi.org/10.1017/9781316027073.

Olson, D. R. 1988. "On the Origins of Beliefs and Other Intentional States in Children." In *Developing Theories of Mind*, edited by J. W. Astington, P. L. Harris, and D. R. Olson, 414. Cambridge University Press.

Parise, E., and G. Csibra. 2012. "Electrophysiological Evidence for the Understanding of Maternal Speech by 9-Month-Old Infants." *Psychological Science* 23, no. 7: 728–733. https://doi.org/10.1177/0956797612438734.

Paunov, A. M., I. A. Blank, and E. Fedorenko. 2019. "Functionally Distinct Language and Theory of Mind Networks Are Synchronized at Rest and During Language Comprehension." *Journal of Neurophysiology* 121, no. 4: 1244–1265. https://doi.org/10.1152/jn.00619.2018.

Perner, J., S. R. Leekam, and H. Wimmer. 1987. "Three-Year-Olds' difficulty With False Belief: The Case for a Conceptual Deficit." *British Journal of Developmental Psychology* 5, no. 2: 125–137. https://doi.org/10.1111/j.2044-835X.1987.tb01048.x.

Pléh, C. 2000. "Modularity and Pragmatics." *Pragmatics Quarterly Publication of the International Pragmatics Association (IPrA)* 10, no. 4: 415–438. https://doi.org/10.1075/prag.10.4.04ple.

Politzer-Ahles, S., R. Fiorentino, X. Jiang, and X. Zhou. 2013. "Distinct Neural Correlates for Pragmatic and Semantic Meaning Processing: An Event-Related Potential Investigation of Scalar Implicature Processing Using Picture-Sentence Verification." *Brain Research* 1490: 134–152. https://doi.org/10.1016/j.brainres.2012.10.042.

Premack, D., and G. Woodruff. 1978. "Does the Chimpanzee Have a Theory of Mind?" *Behavioral and Brain Sciences* 1, no. 4: 515–526. https://doi.org/10.1017/S0140525x00076512.

Rabovsky, M., S. S. Hansen, and J. L. McClelland. 2018. "Modelling the N400 Brain Potential as Change in a Probabilistic Representation of Meaning." *Nature Human Behaviour* 2, no. 9: 693–705. https://doi.org/10.1038/s41562-018-0406-4.

Rabovsky, M., A. Lopopolo, and D. J. Schad. 2024. "Interindividual Differences in Predicting Words Versus Sentence Meaning: Explaining N400 Amplitudes Using Large-Scale Neural Network Models." *Proceedings of the Annual Meeting of the Cognitive Science Society* 46: 276–281.

Reboul, A., and J. Moeschler. 1998. *La Pragmatique Aujourd'hui. Une Nouvelle Science de la Communication*. Le Seuil.

Regel, S., and T. C. Gunter. 2017. "Don't Get Me Wrong: ERP Evidence From Cueing Communicative Intentions." *Frontiers in Psychology* 8, no. September: 1–11. https://doi.org/10.3389/fpsyg.2017.01465.

Regel, S., T. C. Gunter, and A. D. Friederici. 2011. "Isn't It Ironic? An Electrophysiological Exploration of Figurative Language Processing." *Journal of Cognitive Neuroscience* 23, no. 2: 277–293. https://doi.org/10.1162/jocn.2010.21411.

Rubio-Fernandez, P. 2021. "Pragmatic Markers: the Missing Link Between Language and Theory of Mind." *Synthese* 199, no. 1–2: 1125–1158. https://doi.org/10.1007/s11229-020-02768-z.

Rueschemeyer, S.-A., T. Gardner, and C. Stoner. 2015. "The Social N400 Effect: How the Presence of Other Listeners Affects Language Comprehension." *Psychonomic Bulletin & Review* 22, no. 1: 128–134. https://doi.org/10.3758/s13423-014-0654-x.

Ruffman, T., L. Slade, K. Rowlandson, C. Rumsey, and A. Garnham. 2003. "How Language Relates to Belief, Desire, and Emotion Understanding." *Cognitive Development* 18, no. 2: 139–158. https://doi.org/10.1016/S0885-2014(03)00002-9.

Sabbagh, M. A., and D. A. Baldwin. 2001. "Learning Words From Knowledgeable Versus Ignorant Speakers: Links Between Preschoolers' Theory of Mind and Semantic Development." *Child Development* 72, no. 4: 1054–1070. https://doi.org/10.1111/1467-8624.00334.

Schlenker, P. 2016. "The Semantics–Pragmatics Interface." In *The Cambridge Handbook of Formal Semantics*. Cambridge University Press. https://doi.org/10.1017/CBO9781139236157.023.

Schurz, M., J. Radua, M. Aichhorn, F. Richlan, and J. Perner. 2014. "Fractionating Theory of Mind: A Meta-Analysis of Functional Brain Imaging Studies." *Neuroscience and Biobehavioral Reviews* 42: 9–34. https://doi.org/10.1016/j.neubiorev.2014.01.009.

Schurz, M., J. Radua, M. G. Tholen, et al. 2020. "Toward a Hierarchical Model of Social Cognition: A Neuroimaging Meta-Analysis and Integrative Review of Empathy and Theory of Mind." *Psychological Bulletin* 147, no. 3: 293–327. https://doi.org/10.1037/bul0000303.

Scott, R. M., and R. Baillargeon. 2017. "Early False-Belief Understanding." *Trends in Cognitive Sciences* 21, no. 4: 237–249. https://doi.org/10.1016/j.tics.2017.01.012.

Shain, C., A. Paunov, X. Chen, B. Lipkin, and E. Fedorenko. 2023. "No Evidence of Theory of Mind Reasoning in the Human Language Network." *Cerebral Cortex* 33, no. 10: 6299–6319. https://doi.org/10.1093/cercor/bhac505.

Southgate, V., and A. Vernetti. 2014. "Belief-Based Action Prediction in Preverbal Infants." *Cognition* 130, no. 1: 1–10. https://doi.org/10.1016/j.cognition.2013.08.008.

Sperber, D., and D. Wilson. 1986. *Relevance: Communication and Cognition*. Blackwell.

Sperber, D., and D. Wilson. 2002. "Pragmatics, Modularity and Mind-Reading." *Mind & Language* 17, no. 1–2: 3–23. https://doi.org/10.1111/1468-0017.00186.

Sperber, D., and D. Wilson. 2026. "Rethinking Ostensive Communication in an Evolutionary, Comparative, and Developmental Perspective." *Psychological Review* 133, no. 2: 315–338. https://doi.org/10.1037/rev0000565.

Stahl, D., E. Parise, S. Hoehl, and T. Striano. 2010. "Eye Contact and Emotional Face Processing in 6-Month-Old Infants: Advanced Statistical Methods Applied to Event-Related Potentials." *Brain and Development* 32, no. 4: 305–317. https://doi.org/10.1016/j.braindev.2009.04.001.

Tomasello, M. 2008. *Origins of Human Communication*. MIT Press. https://doi.org/10.7551/mitpress/7551.001.0001.

Tomasello, M. 2018. "How Children Come to Understand False Beliefs: A Shared Intentionality Account." *Proceedings of the National Academy of Sciences* 115, no. 34: 8491–8498. https://doi.org/10.1073/pnas.1804761115.

Tomasello, R., C. Kim, F. R. Dreyer, L. Grisoni, and F. Pulvermüller. 2019. "Neurophysiological Evidence for Rapid Processing of Verbal and Gestural Information in Understanding Communicative Actions." *Scientific Reports* 9, no. 1: 1–17. https://doi.org/10.1038/s41598-019-52158-w.

Troyer, M., and M. Kutas. 2020. "Harry Potter and the Chamber of What?: The Impact of What Individuals Know on Word Processing During Reading." *Language, Cognition and Neuroscience* 35, no. 5: 641–657. https://doi.org/10.1080/23273798.2018.1503309.

Troyer, M., K. McRae, and M. Kutas. 2022. "Wrong or Right? Brain Potentials Reveal Hemispheric Asymmetries to Semantic Relations During Word-By-Word Sentence Reading as a Function of (Fictional) Knowledge." *Neuropsychologia* 170, no. (March): 108215. https://doi.org/10.1016/j.neuropsychologia.2022.108215.

Troyer, M., T. P. Urbach, and M. Kutas. 2020. "Lumos!: Electrophysiological Tracking of (Wizarding) World Knowledge Use During Reading." *Journal of Experimental Psychology: Learning, Memory, and Cognition* 46, no. 3: 476–486. https://doi.org/10.1037/xlm0000737.

Urbach, T. P., K. A. DeLong, W.-H. Chan, and M. Kutas. 2020. "An Exploratory Data Analysis of Word Form Prediction During Word-By-Word Reading." *Proceedings of the National Academy of Sciences* 117, no. 34: 20483–20494. https://doi.org/10.1073/pnas.1922028117.

Van Berkum, J. J. A. 2009. "The Neuropragmatics of "Simple" Utterance Comprehension: An ERP Review." In *Semantics and Pragmatics: From Experiment to Theory*, edited by R. Breheny, U. Sauerland, and K. A. Loparo, 276–316. Palgrave Macmillian.

Van Berkum, J. J. A., B. Holleman, M. Nieuwland, M. Otten, and J. Murre. 2009. "Right or Wrong?" *Psychological Science* 20, no. 9: 1092–1099. https://doi.org/10.1111/j.1467-9280.2009.02411.x.

Van Berkum, J. J. A., D. Van Den Brink, C. M. J. Y. Tesink, M. Kos, and P. Hagoort. 2008. "The Neural Integration of Speaker and Message." *Journal of Cognitive Neuroscience* 20, no. 4: 580–591. https://doi.org/10.1162/jocn.2008.20054.

Van Lancker Sidtis, D. 2006. "Does Functional Neuroimaging Solve the Questions of Neurolinguistics?" *Brain and Language* 98, no. 3: 276–290. https://doi.org/10.1016/j.bandl.2006.05.006.

Van Petten, C., and B. J. Luka. 2006. "Neural Localization of Semantic Context Effects in Electromagnetic and Hemodynamic Studies." *Brain and Language* 97, no. 3: 279–293. https://doi.org/10.1016/j.bandl.2005.11.003.

Vouloumanos, A., A. Martin, and K. H. Onishi. 2014. "Do 6-Month-Olds Understand That Speech Can Communicate?" *Developmental Science* 17, no. 6: 872–879. https://doi.org/10.1111/desc.12170.

Vygotsky, L. S. 1986. *Language and Thought*. MIT Press.

Westley, A., Z. Kohút, and S. A. Rueschemeyer. 2017. ""I Know Something You Don't Know": Discourse and Social Context Effects on the N400 in Adolescents." *Journal of Experimental Child Psychology* 164: 45–54. https://doi.org/10.1016/j.jecp.2017.06.016.

White, K. R., S. L. Crites, J. H. Taylor, and G. Corral. 2009. "Wait, What? Assessing Stereotype Incongruities Using the N400 ERP Component." *Social Cognitive and Affective Neuroscience* 4, no. 2: 191–198. https://doi.org/10.1093/scan/nsp004.