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14-month-old infants detect a semantic mismatch when occluded objects are mislabeled

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Abstract

When infants start mastering their first language, they may start to notice when words are used incorrectly. Around 14-months of age, infants detect incorrect labeling when they are presented with an object which is labeled while still visible. However, things that are referred to are often out of sight when we communicate about them. The present study examined infants' detection of semantic mismatch when the object was occluded at the time of labeling. Specifically, we investigated whether mislabeling that referred to an occluded object could elicit a semantic mismatch. We showed 14-month-old Danish-speaking infants events where an onscreen agent showed an object and then hid it in a box. This was followed by another agent's hand pointing at the box, and a concurrent auditory category label played, which either matched or did not match the hidden object. Our results indicate that there is an effect of semantic mismatch with a larger negativity in incongruent trials. Thus, infants detected a mismatch, as indicated by a larger n400, when occluded objects were mislabeled. This finding suggests that infants can sustain an object representation in

memory and compare it to a semantic representation of an auditory category label.

1 | INTRODUCTION

In communication, we often refer to things that are not in our immediate surrounding or visible at the time. Absent referents can be objects or people we expect to appear, things we imagine or that may not exist in any physical form, or things that have been previously observed. From about 12 months of age, infants perceive referential communication as a social cue that generates expectations about the presence of a referent (Butterworth & Jarrett, 1991; Thoermer & Sodian, 2001). For example, they expect an object to be present when someone is pointing or gazing in a particular direction and understand pointing to convey communicative intentions about an object (Csibra & Volein, 2008; Pätzold & Liszkowski, 2019). A referential act not only sets up an expectation for any object to be present, but one regarding the presence of a particular object or object kind. For example, if 13-month-old infants see a person pointing behind one of two occluders and they utter an object label, infants show surprise when a different object is revealed at the pointed-to location (Gliga & Csibra, 2009). This has been interpreted as evidence that by this age, infants understand the referential nature of deictic gestures. That is, they understand that deictic gestures combined with words refer *to* something—and understand reference to things that may be encountered later, guiding them to search for the expected referent (see also Osina et al., 2018).

Understanding communication about previously observed absent referents is also evident from around 12 months of age, when infants search for things that others talk about, or begin themselves to produce reference to out of view objects or people (Bohn et al., 2015; Ganea & Saylor, 2013a, 2013b; Huttenlocher, 1974; Liszkowski et al., 2007, 2009). Intimately linked with pragmatics, such reference to absent entities from early on is based on what information the communicative partner may have had access to or believes to be the case, both when infants interpret others' requests (Saylor et al., 2011; Southgate et al., 2010) and when they themselves communicate about objects that are out of view (Bohn et al., 2018). Such referential understanding has consequences for linguistic development and may support, for example, the learning of novel words from dynamic and potentially impoverished or underspecified input. For example, infants can infer the label of an object when it is uttered with a reference to the previous location of that object (Samuelson et al., 2011). While initially they may rely on perceptual anchors to access representations of objects (Gallerani et al., 2009; Ganea & Saylor, 2013b; Osina et al., 2013, 2014; Saylor, 2004), by at least 14–16 months of age infants appreciate the link between words and mental representations (Hendrickson & Sundara, 2017; Luchkina et al., 2020) and use this ability to learn novel labels of *absent novel* objects (Luchkina & Waxman, 2021), and a few months later also to learn from verbal testimony (Ganea et al., 2007). Infants are thus from a young age adept at identifying referents whether in their physical manifestations or in the form of mental representations, and readily link words to the intended target of communication even if it is hidden at the time.

One question that remains open is how exactly infants come to understand the reference. Absent reference studies typically entail a label followed by either showing the infant a matched or mismatched object (Gliga & Csibra, 2009; Osina et al., 2018), and measure infants' behavioral response. The outcome measure is often infant' continued search when the object(s) they encounter don't match the category label they heard. This suggests that they understand labels as category-defining and appreciate the reference to an absent object to refer to members of that category (Osina et al., 2018). However, it is difficult to know only from infants' behavior whether they understand that reference was made to a particular object and thus can be incorrect. For example, when encountering an object do they detect it as not matching, or do they continue until they find one that matches? It is possible that the auditory reference evokes a representation of the object that matches the heard label—and invites a search for a corresponding referent (i.e., a matching category member). If reference simply invites a search of available representations, then if this search doesn't yield any success, it will lead to no candidate referents (and thus maybe to further continued search) but will not lead to a mismatch. Alternatively, infants may expect a label to refer to an object, compare the label against the object category information, and detect if someone makes an incorrect reference—a reference that does not match the object. This interpretation is largely in line with the literature on understanding absent reference at this age, however, a more direct probe is needed to test infants' response to *incorrect* reference toward a hidden object.

For example, in Gliga and Csibra (2009), infants' behavior suggests that they expected to find a specific object (e.g., a duck) in the indicated location. This could be because they understand the referential nature of the hidden labeling episode. In other words, they understand that the deictic gesture is a communication that carries referential intent to (a particular) hidden referent. Alternatively, upon hearing the label "duck," infants may expect to see a duck. Since their attention is biased to the indicated location by the point, longer looking to the outcome in which the duck is revealed on the other side may reflect their continued search for the duck when they don't see it at the indicated location. In this study, the "two-source" control was included to rule out that infants were simply expecting to find a duck without understanding the referential nature of these two kinds of communicative signals. However, a null result is difficult to interpret, and a skeptic might object that the two sources of information is rather unusual, may have been unexpected and thus difficult for infants to interpret, distracting them from the indicated location and leading to a null result.

An alternative way of investigating whether infants understand that words and deictic gestures co-refer, is to look at what happens in the brain. Specifically, the N400 ERP component is modulated by semantic match such that if the listener detects a mismatch between a label and its referent, a larger amplitude N400 can be observed (Kappenman & Luck, 2011; Kutas & Federmeier, 2011), indicated by a greater negative shift in the ERP waveform typically between 400 and 600 ms after word onset (the N400 effect). Thus, one could hypothesize that if infants understand that the communication refers to an absent referent (e.g., an object now out of sight, inside a box), a label that does not match the hidden referent (e.g., the label duck when the object placed in the box was a shoe) should be detected in the N400.

The N400 has been used to demonstrate that infants detect incorrect reference when objects are visible. Already at 9 months, infants show the N400 effect if they receive extensive familiarization with word-object pairs (Junge et al., 2012), or if objects are incorrectly named live by their mother, but not when they are labeled by an experimenter (Parise & Csibra, 2012). At the same age, they also respond with a higher N400 to seeing unexpected events in action sequences (Reid et al., 2009), suggesting that it is elicited by semantic congruity beyond words. Somewhat later, at 12 months the N400 effect is elicited also by a stranger's labeling but only in high word producers (Friedrich & Friederici, 2010). Most studies with young infants investigated visually evoked ERPs by measuring infants' response to incongruent images that were preceded by word primes. Typically, around 14 months, infants also show an auditory N400 effect when a visible object is subsequently incorrectly labeled (Forgács et al., 2019; Friedrich & Friederici, 2005, 2008; Junge et al., 2012). However, in all the object-labeling paradigms the object was visible during (or after) it was labeled. It is therefore unknown whether infants detect a mismatch if this involves sustaining the previously observed object's identity in memory and compare it to an object label in mental space, and thus whether they would show the N400 effect if the object is occluded at the time of labeling.

The present study thus looked at whether 14-month-old infants detect a semantic violation, indexed by an N400 effect, when an occluded familiar object is labeled incongruently. Our aim was to detect if infants are sensitive to incorrect reference to a hidden object. With this we also aimed to go beyond behavioral measures such as (non-)verbal search for an object. While infants who do show these responses are interpreted as not understanding the reference, they may simply not respond with explicit behavior. Measuring infants' EEG response provides an alternative to these overt behaviors. The 14-month-old age group was chosen based on previous studies using the N400 component as an index of semantic mismatch (Forgács et al., 2019; Friedrich & Friederici, 2005, 2008), and research showing a significant comprehension advance around 14 months of age (Bergelson, 2013). Infants observed videos where various familiar objects were first presented, and then occluded. The hidden object was then pointed toward and labeled either congruently or incongruently. We measured infants' electrophysiological brain activity using EEG and analyzed the N400 event-related potential when infants heard the label. We reasoned that if infants detect a semantic mismatch, they should show a larger negative activation around 400–600 ms after word onset (Forgács et al., 2019) in response to incongruent than congruent trials.

2 | METHOD

The study was pre-registered on the Open Science Framework: https://osf.io/y93kd?view_only=2a0470ccbbe84596b85a4%200c32783ad68. Where we diverged from the pre-registration we explain in the corresponding section *(age group, analysis time window, gender as factor).*

2.1 | Participants

Twenty-eight full-term, 14-month-old infants (mean age: 443 days; range: 429–458 days, 15 female) took part in this study. We choose a slightly older age group than the pre-registered 12–13-months because of the well-documented slightly delayed vocabulary development in Danish speaking infants compared to infants of other languages (Bleses et al., 2008, 2011; Trecca et al., 2020). Data from our e-mail survey prior to the study also indicated that 12–13-month-old Danish infants understand few nouns. Finally, the 14–15-month age group has been found to show an N400 effect in a paradigm that is most similar to the present study (Forgács et al., 2019).

All infants were Danish monolinguals (according to parent report, infants were exposed to less than 15% of any other languages), from a middle-size European city and were predominantly from white middle-income families, reflective of the local population. Participants received a small gift for participating. The sample size was pre-registered based on previous studies investigating N400 effects in infants (Forgács et al., 2019; Friedrich & Friederici, 2005, 2008, 2010; Junge et al., 2012; Parise & Csibra, 2012) and a power analysis (using G-power). We determined a sample size of 28 included participants based on Parise and Csibra (2012) who used a paradigm that included occluded objects, and assuming a power of 0.9, an alpha of .05, and $f = 0.4$. We took this more conservative effect because the task of detecting mismatch to an occluded object is likely to be more difficult. A further 29 infants participated but were excluded from the final data analysis due to fussiness ($n = 11$) not having at least 10 artifact-free trials per condition ($n = 16$), or the child being exposed to a second language more than 15% according to parent report ($n = 1$). While this criterion was not pre-registered, according to common practice one further infant was excluded as they were born more than 4 weeks pre-term ($n = 1$).

2.2 | Procedure

Prior to the experiment, we explained the procedure to the parents and received their informed consent. The present study was conducted according to guidelines laid down in the Declaration of Helsinki, with written informed consent obtained from a parent or guardian for each infant before any assessment or data collection. Ethical approval was obtained from the ethics committee of the Department of Psychology at the University of Copenhagen. Due to the covid-19 regulations, the experimenters wore face shields and other safety measures were applied which were approved by the university/department.

Prior to the start of testing, infants were shown each of the physical objects used in the video recordings. One experimenter showed the object to the infant for ca 5–10 s and parents were asked to label each object with the label corresponding to the label used in the video recordings. Infants were allowed to touch and explore the objects if they wished. This part took about 3–4 min and was done in order to familiarize infants with these particular exemplars of objects they were otherwise estimated to know the label for.

During the EEG recording, infants were seated on their parent's lap in front of a monitor. Parents were instructed to close their eyes or look down onto the infant's head during the experiment. Video recordings were shown on a 24-inch monitor (display area: 53.13 × 29.88 cm) situated approximately 1 m in front of the infant. We used Psychtoolbox 3.0.15 via MATLAB (2018b) for stimulus presentation to control sound playback and to send EEG markers at the onset of word labels to NetStation 5.4.2 which recorded the EEG. We used two cameras to video record the infants to assess their attention during the recording and to check for eye and body movements during subsequent analysis. The EEG session lasted 10–15 min, depending on the infant's interest.

After the study, parents were asked to fill out two questionnaires. One questionnaire concerned basic demographic information (see Supporting Information S1), including the languages the child was exposed to. The other was a list of 19 words where parents were instructed to mark whether they believed their child understood the words on a Likert scale of No, Maybe, and Yes. These 19 words included the 16 object labels used in the video recording, 2 that were left out after piloting, plus the child's own name.

2.3 | Stimuli

Infants were shown four familiarization trials using different objects from those shown in the test trials. These were followed by a maximum of three blocks of test trials, each containing 24 different trials (description of test trials and randomization see below). Prior to each trial both in familiarization and test a fixation stimulus accompanied by a short sound appeared on the screen to direct the infant's attention to the monitor. There was a 500–700 ms variable interval before the fixation stimulus, then when the infant was attentive the experimenter initiated the trial which started after a 300–500 ms delay. If the infant became inattentive, a rotating spiral accompanied by music appeared until they looked at the screen.

The four familiarization trials served the purpose of familiarizing infants with labeling events, but without occlusion or hiding of the object. Infants saw an actor facing a familiar object on top of a box. The actor lifted the object, showed it toward the camera, and put it back on top of the box. A hand (of another person, whose body was not visible) appeared, pointed to the object and a speaker's voice uttered an exclamation and article and then labeled the object always congruently, for example, "Wow!.. A bird." Each familiarization trial included a different object, none of which appeared in test trials, to avoid spillover effects.

During the test trials (see Figure 1, for an example see: https://osf.io/t3qck/), infants saw the same actor facing a familiar object on top of a box. The actor held up the object, looked into the camera, and then put it into the box and closed the lid. A hand appeared from the side, pointed to the box, and then a speaker's voice uttered an exclamation and article and then labeled the object congruently or incongruently.

2.4 | Presentation sequence

Infants saw a maximum of three blocks, and trials were pseudo-randomized per block. During a block of 24 trials, the 12 different objects shown in the test trials occurred twice per block and were pseudo-randomly presented such that the second instance of the same object occurred at least four trials after the first (i.e., three other objects between the two occurrences of the same object). The 12 labels were also presented twice per block and were pseudo-randomized, such that there were no more than two consecutive congruent or incongruent trials and within each block, the two instances of the same label were at least three trials apart, and randomization also considered them relative to the objects such that and half of the trials per block included congruent labeling and the other half included incongruent labeling. Congruent labels were the label matching the object, incongruent labels were randomly drawn from the remaining labels, but only used once per block as incongruent; thus, all labels appeared twice per block, once as congruent and once as incongruent (i.e., twice every 24 trials). The first trial was always congruent. For a sample object-word sequence, see Supporting Information S1.

2.5 | Labels

The objects were labeled in an (exclamation + article + word) format, for example,: "Look, a shoe!" (in Danish "Se, en sko"). The same article was used for all words (all words were "en-words" in that the correct article was "en," which is the majority of Danish words) and thus the article was not predictive on which labels could come after. Four objects were used during familiarization trials, while 12 other objects were used during the test trials. We used familiar objects the names of which infants at this age presumably have knowledge of (Bergelson & Swingley, 2013; Bleses et al., 2008; Forgács et al., 2019; Gliga et al., 2010; Wehberg et al., 2007). For the full list of labels that were presented to the infants see Supporting Information S1. We decided which objects and labels to use based on previous studies with infants around this age group in other languages (Forgács et al., 2019; Friedrich & Friederici, 2005; Parise &

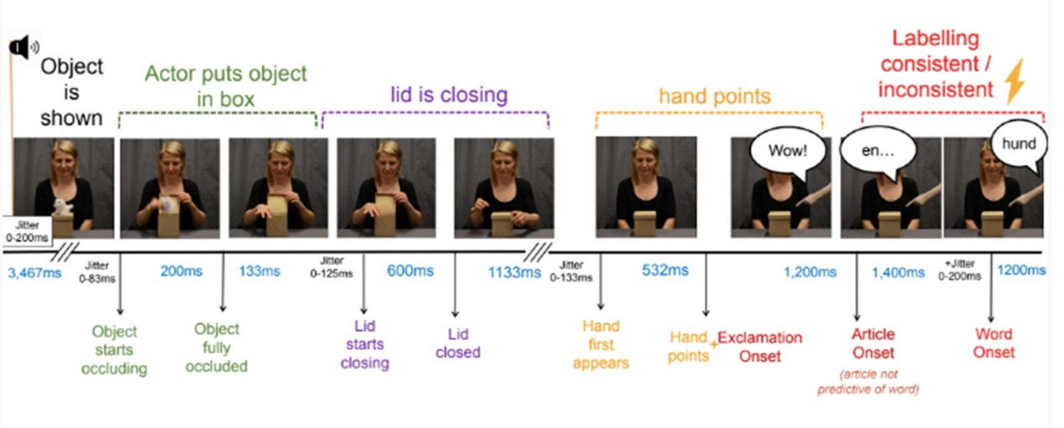

FIGURE 1 Schematic depiction of a test trial structure.

Csibra, 2012), as well as the Stanford Word Bank and the Danish CDI (Bleses et al., 2008; Frank et al., 2017). Prior to the study, in an e-mail survey of families in our database, 60 parents of 14-month-old infants rated whether they thought their child understood a list of object words, and we selected the words that were most likely to be known at this age by Danish infants.

We used audio recordings of the object labels and used three different exclamations: "Look!," "Oh!," or "Wow!" (in Danish "Se," "Ooh" and "Wow") with a native Danish female speaker in an infant-directed manner.

2.6 | EEG recording and analysis

We recorded the EEG continuously via a 124-channel Geodesic Sensor Net at 500 Hz sampling rate referenced to the vertex (Cz). A 128-channel net was used for a few participants who had head circumferences between 48 and 51 cm. Of the 128 channels, 124 were used and four additional channels were disregarded for the purposes of analysis. EEG data were analyzed using Net Station 5.4.2 (Electrical Geodesics Inc.). The raw data was filtered with a 0.1 Hz high-pass, and 30 Hz low-pass filter, and for the main analysis segmented into 1600 ms sections, starting at 400 ms before the word onset (audio playback) and lasting until 1200 ms after word onset in each trial. The data was segmented into two categories: Congruent or Incongruent.

Artifact detection was done both automatically (blinks, eye movements and bad channels), as well as manually. Segments with more than 20 channels (>~15% of the channels) containing artifacts were also excluded. Video recordings from the two cameras confirmed that the infants were attentive during the included segments. Bad channels were interpolated in the remaining segments. Baseline correction from the period of −200 to 0 ms of word onset was used and the segments were re-referenced to the average reference. Infants that were included in the final analysis had a minimum of 10 trial per condition and contributed an average of 12.8 trials in the Congruent condition (SD = 3.5; range: 10–23), and 13 trials in the Incongruent condition (SD = 3.7; range: 10–23). Based on previous findings with similar paradigms (Forgács et al., 2019; Friedrich & Friederici, 2005; Parise & Csibra, 2012), our region of interest (ROI) encompassed the following nine electrodes in the parietal region: 61, 62, 67, 71, 72, 76, 77, 78, 84, corresponding to the area around Pz in the 10/20 system.

3 | RESULTS

3.1 | N400 effect in response to incongruent labeling

As our main analysis, we assessed infants' ERP response to the incongruent versus congruent labeling. For the purpose of the statistical analyses, based on previous findings (Forgács et al., 2019; Friedrich & Friederici, 2005; Parise & Csibra, 2012) we defined nine parietal electrodes as the ROI (see above). To focus our analyses to the time window recent studies have found a N400 effect in similar paradigms (e.g., Forgács et al., 2020; for a recent review see Junge et al., 2012), we analyzed activation between 400 and 600 ms after word onset (instead of the pre-registered time of 400–900) within our ROI, see Figure 2. In the pre-registration we included to look at gender as a factor due to potential differences in vocabulary, but since we did not see any effect in our sample on the number of known words reported ($t(1,26) = 0.909$, $p = .372$, 95% CI [−1.172 3.028]), and no relation between vocabulary and the N400 effect (see Word understanding section), we had no reasons to expect an effect of gender and omitted it from further analyses. All statistical analyses used 2-tailed tests.

We ran a repeated-measures ANOVA with Congruency (congruent, incongruent), Hemisphere (left, right) and Time Bin (400–500 ms, 500–600 ms) as within-subject factors. Most importantly for the question of the present study, there was a statistically significant main effect of Congruency ($F(1, 27) = 4.448$, $p = .044$, $\eta^2 = 0.141$), indicating that the average activation in incongruent trials was overall more negative ($M_{\text{incong}} = -8.9$ μV, $SD = 7.44$) than in congruent trials ($M_{\text{cong}} = -5.48$ μV, $SD = 9.26$), see Figure 2.

There was also a main effect of Time Bin indicating that the average activation showed less negativity over time, regardless of condition ($F(1, 27) = 12.589$, $p = .001$, $\eta^2 = 0.318$, $M_{400\text{–}500} = -8.365$, $SD_{400\text{–}500} = 8.007$, $M_{500\text{–}600} = -5.936$, $SD_{500\text{–}600} = 6.953$), which simply reflects the overall time course of the n400 response (i.e., negativity peaking around 400–500 ms followed by a decrease). There was no main effect of Hemisphere ($F(1, 27) = 0.033$, $p = .857$, $\eta^2 = 001$). Time Bin has been added in the analysis in case the difference between condition was larger or only to be found in part of the overall time window. However, there were no interactions (all p-s > .577), therefore no follow-up analyses were run. In an exploratory manner, we analyzed whether the effect of condition changed over time during the recording session. While visually and numerically the difference between conditions increased with time and from the first to the second half of trials, this was not statistically significant (for details see Supporting Information S1). While there was some variability in the number of trials infants contributed (see EEG recording and analysis section), there was no relation between number of trials contributed and magnitude of N400 effect (Pearson's r (28) = .163, $p = .408$).

As a further analysis, we used cluster-based permutation analysis (Groppe et al., 2011) as a data driven method (see Figure 3). We ran the analysis in the time period 400–600 ms after word onset, a time period where we typically expect N400 effect in infants, and the channels identified by Forgács et al. (2019) whose study was most similar to the present design, extended by one adjacent channel, to account for possible spatial variation in our effect. Then, we used permutation analysis to produce a statistical threshold to compare the cluster sum T-value. We ran 100,000 permutations, and in 95,150 out of these maximum cluster sum T-value was lower than the original one, yielding a p-value of .0485. The full time extent of the cluster detected was 458–583 ms consisting of nine channels (for details of the cluster-based permutation analysis and the spatial extent see Supporting Information S1).

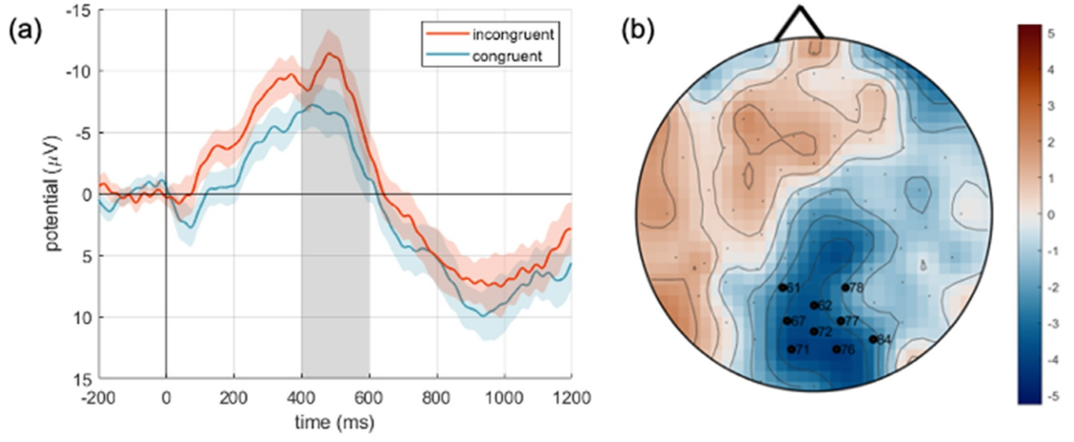

FIGURE 2 Infants' response to the labeling event. (a) ERP response averaged across the nine channels of interest (marked with numbered black dots on part b) in the incongruent and congruent condition where 0 ms marks the word onset and the shaded area indicates +/−1 standard deviation, and (b) topographic plot of the difference between conditions (incongruent-congruent, larger negativity in incongruent condition indicated by blue), averaged across the 400–600 ms time window, with the channels of interest (61, 62, 67, 71, 72, 76, 77, 78, 84) marked with black dots and respective channel numbers.

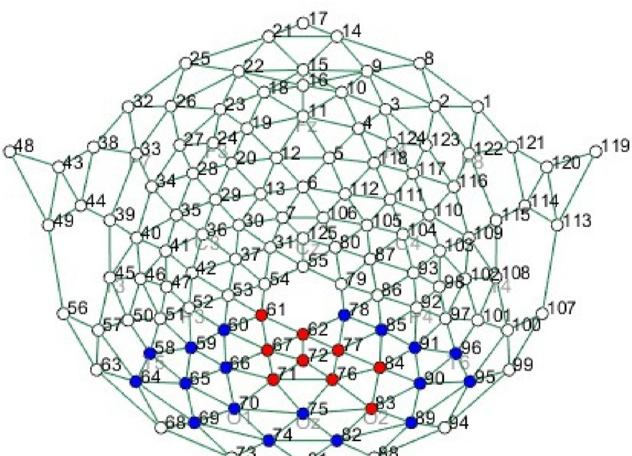

FIGURE 3 Results of the cluster-based permutation analysis. Channels marked red are the cluster detected as significant.

3.2 | Word understanding

To address whether infants' knowledge of the words used in the present study may have influenced their response to the incongruent versus congruent labeling, we analyzed infants' reported understanding of the words used. Overall, there was a significant correlation between the age in days of infants and both average estimate of word understanding (on a scale of 1–3 for each word) and number of words reported as understood (Spearman's $r(57) = .342$, $p = .009$; Spearman's $r(57) = .292$, $p = .028$, respectively) indicating that even over a month period, slightly older infants were reported to have greater receptive language skills. Looking at only the included infants we observed the same trend but presumably because of lack of power there was no statistically significant correlation between the age in days and both average word understanding, and number of words understood (Spearman's $r(28) = .277$, $p = .153$; Spearman's $r(28) = .228$, $p = .244$, respectively).

Infants in the included group were reported to understand on average 15 out of the 19 words (ranging from 9 to 19), and all but one object were reported as more likely to be known than uncertain, indicating that in general our choice of objects was appropriate (the one object reported on average as "maybe" was only used in familiarization). Thus, while Danish infants have been shown to have a delay in vocabulary development and their receptive vocabulary jump has been estimated to around 16 months of age, slightly later than typically in other languages (Bleses et al., 2008; Trecca et al., 2020), the 14-month-olds in our study presumably knew most of these common objects we used.

We also examined the relationship between infants' N400 and vocabulary results. We split our sample by the median according to each participant's number of words marked as known to assess whether there was a difference in the average N400 effect (the average difference between incongruent and congruent conditions) among participants with upper and lower range vocabulary scores (15 and 13 infants, respectively, as six infants had the same score, they were all counted as upper range). This yielded no effect of vocabulary on the N400 effect, $t(26) = -0.06$, $p = .952$, 95% of CI [−6.753, 6.369], Cohen's $d = 8.424$. Overall, we found no relation between parent-report vocabulary and infants' response to incongruent versus congruent labeling of the hidden object.

4 | DISCUSSION

The present study looked at whether 14-month-old infants detect a semantic violation when an occluded familiar object is labeled incongruently. Previously, both adults and infants as young as 9 months of age, were found to exhibit a higher negativity in their ERP response to semantically incongruent events such as a mislabeling of an object, about 400–600 ms after the onset of the word, when the objects were visible during or after labeling (the "N400 effect"). While infants have previously been shown to set up expectations in mental space for hidden referents from verbal reference and anticipate a congruent object to appear subsequently, there has been no evidence to date that they also make the reverse inference. Here, we showed that they detect if a reference toward a previously seen hidden referent is incorrect.

Previous work on hidden reference understanding has revealed that infants from about 11 months orient to a previously seen object if someone refers to it (Ganea, 2005; Huttenlocher, 1974; Osina et al., 2013), suggesting that they readily re-identify the intended target of a reference if it was previously encountered. Labels and deictic gestures also set up referential expectations: for example, from 13 months onward infants look longer if at the location targeted by a pointing accompanied by labeling, an object from a different category appears. Finally, from at least 16 months of age infants continue to search for the referent if they encounter non-referent objects (Osina et al., 2018). Together, these suggest that infants continue to explore if the potential referents they encounter do not match the referential label they hear. What from these studies remained an open question was whether infants expect the reference to correctly apply to a concrete, previously seen object, as identified for example, by a co-referring deictic gesture (a pointing)—and would detect if there is a mismatch between the two. As most other studies measured if infants continue to search or explore until they found a referent that qualified, this left open whether infants expect reference to apply to a particular hidden object (as e.g., identified by a pointing), and respond selectively if the label doesn't match. In the present study we used the N400 electrophysiological measure and showed that when a deictic gesture (pointing) to a hidden object and an accompanying label did not match, infants responded with an increased negativity that is typically found in response to semantic mismatch. This indicates that infants are sensitive to the label incorrectly referring to the target hidden object that they had previously seen. Additionally, while in most studies infants encounter either a matching or a non-matching object, their behavior can always reflect a (mis)match between the activated semantic representation by the label, and the one elicited by the object when they then encounter it. In our study infants never saw the object *after* labeling, therefore the N400 effect found arguably reflects a detection of (mis)match between the label and a mental representation, thus providing a more direct probe of infants' expectation of the label based on the object, rather the other way around.

As previous evidence on N400 in infants comes from scenarios when the labeled object is visible, in those studies the category and label information were readily available at the time when they heard the label. The current study speaks to whether infants at 14 months can hold an object representation in mind and compare it to a later heard auditory label. Detecting a mismatch between the hidden object and a later verbal reference arguably requires detecting a mismatch in mental space, between an activated category information of a hidden referent and the category information derived from a verbal utterance referring to that hidden referent. By at least 12 months infants can use kind/category information to individuate objects and remember object category through occlusion (Xu & Carey, 1996). However, in those cases infants compare a previously observed visual stimulus to a subsequently appearing one (Xu & Carey, 1996) or infer the presence of two objects from two distinct labels (Xu, 2002; Xu et al., 2005). To interpret a label as referring to a previously seen hidden object, it must be based on conceptual information stored about the referent. Communicative acts such as pointing have been shown to elicit activation of object categories from 12 months onwards, at least in case of visually available objects (Pomiechowska et al., 2021). The present study showed that, when prompted through a verbal reference, 14-month-old infants could activate the conceptual category information stored in memory about an occluded object and detect a mismatch when the label was inconsistent with that category information.

The fact that the objects were not visible at the time of, or after, labeling, may also speak to the nature of the N400 effect in the present study, related to explanations underlying the N400 in the literature. In adults, both semantic associations as well as situational or contextual expectancy have been proposed as functional interpretation (for a review see Kutas & Federmeier, 2011), and both have been shown to modulate the N400 (Rabs et al., 2022). In infants, associative mechanisms have been proposed to underlie word learning (Friederici et al., 2013) at least in on-line, short-term contexts (Cosper et al., 2020). In the present study, while we don't directly differentiate between these alternatives, we propose that mechanisms involving context-based expectations related to predictions about input (Lau et al., 2013) plausibly explain our data. While infants have been shown to implicitly label objects (Mani & Plunkett, 2010), which could cause them to associate the label and the box, this kind of association would be most consistent with mismatch response based on auditory similarity (e.g., homophones or words that begin with the same phoneme) and not semantic similarity (category match/mismatch). Additionally, in our study there is no trivial association between the visual scene and the auditory label, unless one expects the pointing toward the box and label to match the object inside the box. The visual scene was always the same (a box in which the referent is hidden), so mismatch detection had to rely on identifying not the pointed-to box, but rather the object it contained, as the intended referent. Therefore, here the N400 effect arguably reflects the referential understanding of labels and their semantic integration.

The presence of an N400 effect in our study therefore also indicates that the box which contained the objects was—over the course of the study—not considered the target referent. While we did not find a significant effect between the first and second half of the trials, the N400 effect was numerically larger in the second half. Speculatively, this could indicate that infants gradually picked up on the pattern of the trials, where the box remained the same but the object inside changed. Thus, infants may have been sensitive to the pragmatic context and identified the most relevant interpretation of the communication to be referring to the object inside. If this is the case, one could argue that communicatively induced referential expectations (e.g., Marno et al., 2015; Parise & Csibra, 2012) provide infants with a top-down mechanism that, opposite to a perceptually based bottom-up one (e.g., Twomey et al., 2018), drives their attribution of meaning to the words they hear. As the N400 effect has been elsewhere argued to reflect a mismatch with expectations not just to linguistic stimuli but also more broadly (Gallagher et al., 2014; Reid et al., 2009), future studies could rule out whether non-referential cues such as other stimuli associated with the objects, or simply hearing a label without pointing and exclamation (“look!”) would similarly elicit the effect we observed.

At an age when their receptive vocabulary is starting to undergo a rapid expansion, infants readily used their vocabulary to understand labeling of hidden objects they have seen just before. This capacity is essential when interpreting referential communication where speakers often refer to objects currently out of sight and may contribute to language learning. While in our study there was no relation with the vocabulary measure, the objects selected were intentionally ones that most infants were likely to know, and we only asked parents to rate these. In other studies, the N400 effect was found to be related to vocabulary measures (Friedrich & Friederici, 2004). It is thus an open question if mismatch between a hidden referent and the auditory label would relate to more comprehensive vocabulary measures. In the absence of such evidence, it remains a possibility that the N400 effect observed in the present study is independent of vocabulary size, in that as long as infants understand (a sufficient number of) the words in question, they also detect when these are used in an incongruent or unexpected way.

Together, the current study showed that 14-month-old infants expect a referential act to refer to a previously observed object and responded with a larger N400 if the reference was unexpected, in that the label did not match the object which was the target of the reference. This suggests that not only can they search for a (potentially out of sight) target of a reference when they hear a label, but they maintain mental representations of things around them, retrieve these as targets of communicative acts, and expect deictic gestures and labels to correctly co-refer to the target.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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