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**Title:** Infants' preferences for native speakers are associated with an expectation of information

**Short title:** Infants choose optimal teachers

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## **Abstract**

Humans' preference for others who share our group membership is well documented, and this heightened valuation of in-group members seems to be rooted in early development. Before 12 months of age, infants already show behavioural preferences for others who evidence cues to same-group membership such as race or native language, yet the function of this selectivity remains unclear. We examine one of these social biases, the preference for native speakers, and propose that this preference may result from infants' motivation to obtain information, and the expectation that interactions with native speakers will provide better opportunities for learning. To investigate this hypothesis, we measured EEG theta activity, a neural rhythm shown to index active and selective preparation for encoding information in adults. In Study 1, we established that 11-month-old infants exhibit an increase in theta activation in situations when they can expect to receive information. We then utilised this neural measure of anticipatory theta activity to explore 11-month-olds' expectations when facing social partners who either speak infants' native language, or a foreign tongue (Study 2). A larger increase in theta oscillations was observed when infants could expect to receive information from the native speaker, indicating infants were preparing to learn information from the native speaker to a greater extent than the foreign speaker. While previous research had demonstrated that infants prefer to interact with knowledgeable others, the current experiments provide the first evidence that such an information seeking motive may also underpin infants' demonstrated preference for native speakers.

## **Significance statement**

This paper addresses the possible developmental origins of humans' preference for native speakers. Infants' preference to attend to someone speaking their native language is well documented and has been interpreted as a developmental precursor of our adult tendency to divide the social world into groups, preferring members of one's own group and disavouring others. Here we propose that this preference may originate from infants' desire to acquire information, and therefore preferentially interact with social partners who are more likely to provide them with relevant learning opportunities. We demonstrate that 11-month-old infants indeed expect to receive information from native as opposed to foreign speakers, suggesting that infants' selective social interactions may be driven by their motivation to learn.

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## **Introduction**

Humans' preference for others that we perceive as sharing our group membership is well documented (1), but its function remains unclear. What seems clear is that heightened valuation of in-group members has its roots early in development. By at least the end of the first year of life, human infants already show a preference for others who evidence cues to same-group membership such as race (2) and native language (3). Not only do infants prefer to look at, and interact with same-group members, they also show a preference for the conventions endorsed by them (4–6).

Infants' social selectivity is not, however, restricted to others who exhibit cues to same-group membership. From birth, infants prefer to direct their attention towards someone making direct eye contact with them (7), and communicating with them using infant-directed speech (8), and by 6 months of age, infants use the presence of these cues to guide their own visual exploration (9). Later, infants also use perceived competency and reliability to identify preferred social partners. For example, whether or not someone uses an object in its conventional way (10), or provides reliable information for the infant (11), influences the extent to which infants attend to and follow that person's actions.

Infants' preference for both direct gaze and infant-directed speech has been proposed to reflect an adaptation to ensure optimal transmission of cultural knowledge (12, 13). Under this view, these behaviours serve as cues for infants to identify potential teachers (7, 14), and attend to what is being taught (9). For example, only when someone's gaze shift towards an object is preceded by direct gaze, or infant-directed speech, do infants shift their own gaze towards the same object, indicating a behavioural selectiveness that would facilitate

learning about the object in one case, but not the other (9). Similarly, their sensitivity to, and preference for, reliable and competent others has been proposed to support social learning by ensuring that infants primarily learn from people providing accurate and relevant information (10, 11).

Here we propose that infants' preference for others exhibiting cues to same-group membership, specifically native language, may reflect the same strategy of directing attention towards the best available source of information. Allocating more attention to someone speaking the same language (3, 15), would be a sensible learning strategy, given that language can indicate a common culture and a native speaker is therefore more likely to convey relevant information than a non-native speaker. Indeed, it has been shown that 2-year-olds expect foreign language use to associate with other cultural knowledge, such as unconventional tool use, supporting the hypothesis that social categories, such as linguistic groups, may be formed based on, and with the function of, defining barriers of culturally shared knowledge (16). Infants' preference for the conventions (6), food preferences (4) and musical tastes (5) conveyed by a native language speaker is consistent with this hypothesis because it is exactly these kinds of arbitrary, culturally-dependent phenomena that a same-group member would be best placed to transmit. Furthermore, while adults and older children are sensitive to arbitrary markers of group membership (17), 1-year-olds only show preferences for in-group members when group membership is defined by indicators that might genuinely convey a person's likelihood of sharing a similar culture, such as food tastes (18). Finally, older children explicitly endorse information provided by native language speakers, suggesting that they view native speakers as better sources of information (19).

While there is indeed considerable evidence consistent with the idea that infants' early social selectivity may result from a common strategy of directing their attention to informative social partners, to our knowledge, there is no direct evidence that infants' documented preference for native over foreign speakers is driven by infants' perception of native speakers as superior sources of information. In the current study, we exploit a putative neural signature of information expectation, EEG theta oscillations, to address this question.

### **Neural signatures of information expectation**

Studies investigating information processing and learning in adults have revealed that an expectation to receive information is associated with EEG oscillatory activity in the theta frequency range (20, 21). When adults can predict when to-be-encoded stimuli will be presented, theta activation is observed in anticipation of stimuli presentation. Furthermore, this anticipatory theta activity, spanning from 4-8Hz in adults, has been shown to predict the degree to which stimuli are subsequently recalled (20–22). This learning-modulating effect is suggested to result from theta oscillations enabling coordinated activity of cortical-hippocampal loops and thus facilitating synaptic plasticity (23). Importantly, theta activity has been shown to be modulated by participants' motivation to learn (24). When encoding was rewarded, the power of theta activity was predictive of subsequent recall only when learning took place with the prospect of a high reward (22). Combined, these findings suggest that theta activity reflects adults' intention to encode information, even before the information is presented, and that this activity in expectation of information leads to superior learning.

The relationship between theta oscillations and learning has recently also been demonstrated in infants. In a study where 11-month-olds freely explored objects, modulations of theta activity (3-5Hz in infants (25, 26)), recorded over the frontal lobe during object exploration, predicted infants' subsequent recognition of these objects at test (26). The effect of theta activity on learning in this study, as well as its location, were consistent with the findings in the adult literature (22, 24), suggesting that theta activity is associated with information encoding in infants, as it is in adults. However, although theta power is associated with subsequent learning in infants (26), it is unknown whether this activity is also associated with infants' *expectation* of information. While some support for this possibility comes from other infant studies that reported theta activity recorded in situations where infants could have been expecting to receive information, such as during sustained anticipatory attention to social stimuli (27), and during infant- as opposed to adult-directed speech (28), the evidence is thus far indirect. Therefore, in order to investigate whether infants' preference for native speakers is associated with expecting information, we first aimed to establish whether expecting information more generally is associated with an increase of theta oscillations in the infant brain.

Thus, in Study 1, we manipulated whether 11-month-old infants could expect to receive information, by contrasting two informants who either did, or did not, provide infants with novel information. Previous studies have shown that infants are sensitive to others' capacity for imparting information, and are able to modulate their behaviour accordingly. For example, infants point to novel objects more when the person for whom they are pointing has shown herself to be a potential informant (29, 30), and the fact that infants learn better when they

are provided with information contingent on their pointing suggests that it is the different expectation of receiving information that modulates the amount of pointing and subsequent learning (30). If theta oscillations are likewise modulated by expectation of receiving information, we predict more theta activity when infants face a social partner that has previously demonstrated herself as likely to provide information.

### **Study 1: Theta activity as a marker of information expectation**

We conducted 2 EEG experiments in which infants observed informative and non-informative experimenters on a large screen, interacting with familiar (Familiarisation phase) and novel objects (Test Phase). The two experimenters (Informant and Non-Informant) differed in whether or not they provided labels for objects (Experiment 1, Label/No-Label); or whether or not they demonstrated functions on objects (Experiment 2, Function/No-Function). In both Experiments, the Non-Informant merely pointed at the objects and said 'Oooh' (Experiment 1), or handled the object (Experiment 2), but did not provide any information. In the Familiarisation phase, both experimenters were presented together and alternated in interacting with the familiar objects in order to establish which of them infants could expect to convey information. In the following Test phase (Figure 1), the experimenters were presented individually with novel objects. Theta oscillations were analysed during an *Anticipation* period of each trial, during which the Informant or Non-Informant was visible behind the novel object, but before which she began interacting with the object. This enabled us to investigate whether theta oscillations indeed index an expectation of information.



## Results & Discussion

Continuous wavelet analysis of baseline-subtracted, artifact-free epochs, in the 1 to 50 Hz range, was performed on clusters of electrodes over the frontal and bilateral temporal scalp locations, where modulations of theta activity were predicted based on previous findings in adults and infants (21, 22, 26, 27). For comparison, activity recorded in bilateral central and occipital recording sites was also entered into the analysis. Baseline corrected data was analysed for amplitude in the 3-5Hz theta frequency range (25, 26), during the latter half of the *Anticipation* period. This analysis period was chosen based on adult findings showing a gradual increase in activity in anticipation of information (22) and visual inspection of time-frequency plots (Figure 2). A repeated measures ANOVA was conducted with Condition (Informant vs. Non-Informant) and Location (Frontal, Temporal, Central and Occipital) as within-subject variables; and Experiment (1, 2) as a between-subjects variable. The analysis revealed a significant main effect of Condition  $F(1,29) = 5.396, p = 0.028, \eta_p^2 = 0.156$ , and Location  $F(3,87) = 6.354, p = 0.001, \eta_p^2 = 0.458$ ; and a significant interaction between Condition and Location,  $F(3,87) = 3.823, p = 0.013, \eta_p^2 = 0.270$ . There was no significant main effect or interactions involving the between-subjects variable Experiment, suggesting that the type of information (labels or functions) that infants could expect did not result in differential theta activation.

To further explore effects of Condition on theta activity recorded over different scalp locations, follow-up paired-samples t-tests were performed on data combining Experiment 1 and 2, comparing theta activity for Informant and Non-Informant conditions in each location separately. As predicted, these tests

revealed that theta amplitude during the *Anticipation* period was significantly higher in the Informant compared with the Non-Informant trials in frontal channels ( $t(30) = 2.785, p = 0.009$ ), and marginally higher in temporal channels ( $t(30) = 1.909, p = 0.066$ ), whereas no differences in theta amplitude between conditions were found in the control areas (central ( $t(30) = 1.458, p = 0.155$ ) or occipital channels ( $t(30) = 0.960, p = 0.345$ )).

The frontal and temporal scalp locations, where differences in amplitude of anticipatory theta oscillations between conditions were observed, are consistent with studies showing theta oscillations in anticipation of information in adults (21, 22). Although learning was not tested in this study, previous studies, which reported theta oscillations over the same scalp locations in adults and infants (21, 22, 26, 31, 32), also reported a predictive relationship between theta activity and subsequent recollection of the presented material. Combined, these studies suggest that the anticipatory theta activity recorded in the current study likely reflects the same active and selective preparatory process for learning (33). Thus, having demonstrated in Study 1 that theta oscillations in the infant brain are modulated by the potential of a social partner to convey information, Study 2 exploits this measure to ask whether infants perceive a native speaker as a better source of information than a non-native speaker.

## **Study 2: Investigating the native speaker preference**

We hypothesised that infants' preference for native speakers is based on their expectation that these interactions will provide better opportunities for learning. If this is the case, greater anticipatory theta activity, indexing expectation of information (Study 1), should be observed when infants could

expect communication from a native versus a foreign speaker. Thus, in Study 2, we used an identical design as in Experiment 1 of Study 1, with the only difference being that one informant labelled the objects in the infants' native language (English) and the other labelled objects in a foreign tongue (Spanish).

## **Results & Discussion**

Paired-samples t-tests, comparing theta amplitude between Native and Foreign speaker test trials, were focused on the two regions identified in Study 1 as exhibiting higher theta amplitude in anticipation of communication received from the Informant compared to Non-Informant. These revealed greater anticipatory theta activity during Native compared to Foreign speaker test trials in bilateral temporal ( $t(13) = 3.211, p = 0.007$ ), but not in the frontal ( $t(13) = 1.157, p = 0.268$ ) recording site.

Given the lack of difference between conditions in the frontal scalp location in Study 2, we wondered whether the scalp topography of the effects might reflect the type of information infants could anticipate receiving. In Study 1, where both experiments were analysed together, we observed a significant difference between conditions in the frontal channels and a marginally significant difference at bilateral temporal channels, but these experiments differed in the kind of information transmitted: infants received either linguistic (Experiment 1) or functional (Experiment 2) information. Thus, to explore further whether the scalp distribution of anticipatory theta activity may differ according to the type of information infants could anticipate receiving, we carried out post-hoc pair-wise t-tests, comparing conditions separately for Experiment 1 and 2 of Study 1. This analysis hinted at a possible task-specific

dissociation between theta activity in anticipation of receiving verbal and non-verbal information. As in Study 2, differences between conditions were only significant in temporal channels for Experiment 1, where infants could expect linguistic information (Label/No-Label,  $t(14) = 2.117, p = 0.054$ ); whereas a significant difference between conditions of Experiment 2 (Function/No-Function) was only found in the frontal region ( $t(14) = 2.952, p = 0.009$ ).

However, when all 3 Experiments of both Study 1 and 2 are entered in an overall repeated measures ANOVA, conducted with Condition (Informant vs. Non-Informant) and Location (Frontal, Temporal) as within-subjects variables; and Experiment (1, 2, 3) as a between-subjects variable, no main effect nor any interactions involving the between-subjects variable Experiment (1, 2, 3) was found. Furthermore, while the results confirmed a main effect of Condition  $F(1,42) = 9.652, p = 0.003, \eta_p^2 = 0.187$ , and a main effect of Location  $F(1,42) = 4.453, p = 0.041, \eta_p^2 = 0.096$ , (driven by the generally larger amplitudes of theta activity in the frontal location), there was no interaction between the two factors. Combined, these results suggest that, while the distribution of activation appears to differ between experiments when examined individually, and might hint at differences in topography of theta activation depending on the content of the anticipated information, these differences do not reach statistical significance when analysed together and should therefore be interpreted with caution and explored further in future research.

Finally, to establish whether the theta activity recorded during the *Anticipation* period differed significantly from baseline, pair-wise comparisons (using one-sample t-tests with Bonferroni correction) were performed. Results revealed the amplitude of theta activation during the *Anticipation* period was

significantly greater than baseline activity in both Frontal and Temporal locations of the Informant conditions (Informant-Frontal:  $t(44) = 5.715$ ,  $p < 0.001$ , corr.; Informant-Temporal:  $t(44) = 4.800$ ,  $p < 0.001$ , corr.) and in Temporal but not in Frontal locations of the Non-informant conditions (Non-Informant-Frontal:  $t(44) = 2.386$ ,  $p = 0.084$ , corr.; Non-Informant-Temporal:  $t(44) = 3.492$ ,  $p = 0.004$ , corr.). See Figure 2 for time-frequency plots and comparisons of activation to baseline for individual experiments.

### **General discussion**

Previous research has shown that infants are remarkably selective when interacting with social partners; they show preferences in who they attend to, interact with, and imitate, based on a variety of characteristics (3, 7, 10). While some of these preferences, such as attention to ostensibly communicating social partners, have been suggested to facilitate infants' learning from others (7, 9, 13), the function of infants' social selectivity based on indicators of group membership, such as spoken language, remained less clear. In contrast to interpretations proposing that infants use language information to assign individuals to social groups and exhibit preferences in accordance with the principle of in-group loyalty (34), we hypothesised that these preferences may instead reflect a strategy of seeking optimal informants. Specifically, we hypothesised that infants' choice of who to interact with is based on whom they perceive can be expected to provide them with learning opportunities.

To investigate whether infants indeed expect information in their social interactions, we measured changes in EEG theta oscillations, which have been suggested to index an active and selective preparation for encoding information

in adults (35). In Study 1, infants exhibited significantly higher theta when they could anticipate the experimenters to provide verbal (Experiment 1) or functional (Experiment 2) information about novel objects, as compared with when they could expect to receive no information. This study thus established anticipatory theta oscillations as an index of information expectation in infants. This neural marker was then utilised in Study 2, which compared infants' expectations when faced with either a native or a foreign speaking experimenter, both of whom were transmitting information about novel objects. Consistent with our hypothesis, infants exhibited significantly more theta activity when they encountered the native speaker. As these differences in theta activity were observed prior to any information being conveyed, our data suggest that infants were expecting and preparing to learn information from the native speaker to a greater extent than the foreign speaker. While previous research had demonstrated that infants prefer to interact with knowledgeable others (29, 30), the current experiments provide the first evidence that such an information seeking motive may also underpin infants' demonstrated preference for native speakers.

However, it is important to note that infants' differing expectation of information from the native and foreign speakers in our study does not imply that infants identified the native speaker as a same-group member and the non-native speaker as an out-group member, nor that infants even acknowledge the existence of different social groups. Our results tell us that infants distinguished the two experimenters based on spoken language, and that they appeared to treat the native and non-native speakers in the same way as they did the informative and uninformative experimenters of Study 1, respectively. We

propose that treating native speakers as superior sources of information provides a plausible explanation for infants' behavioural preferences towards native speakers, identified in previous research. Heightened attention (3, 15), imitative learning (6), as well as preferential endorsement of conventions of native speakers (5, 36), could all result from infants' motivation to learn and obtain information from optimal teachers.

It is a further question *how* infants identify native language speakers as optimal informants. It is plausible that infants' preference for learning from native speakers stems from a preference to learn from others exhibiting familiar characteristics (3). Infants may preferentially attend to and interact with native speakers and other same-group members because their familiar characteristics match previously experienced good informants or, as would be predicted by models of active learning (37, 38), because the information they provide matches an optimal level of discrepancy from their existing knowledge (37), and is therefore easier to embed into infants' prior knowledge, thus enabling better learning progress (38). A bias to attend to familiar others could also explain why infants' preference for same-group members is initially limited to cues which infants are likely to experience often (like language and food preferences) (18), and why the strength or even presence of some of these same-group biases has been shown to depend on infants' early environmental exposure (2, 39, 40). Thus, if infants identify good informants and form social groups based on familiarity, it would be interesting for future research to explore whether preferences and expectations regarding information provision from speakers of different languages would be different in a group of infants growing up in a multilingual environment. Regardless of the mechanism, identifying others who

share one's language and cultural space, and preferring them as sources of information, is likely to be advantageous in terms of constraining infants' attention and cognitive effort to processing information that is most relevant in their cultural environment.

Another interesting question remains as to what is the role of social communication in eliciting infants' expectation of information. In the current studies, both Informants and Non-Informants in all 3 experiments used direct gaze, infant-directed speech and referential gestures. Previous studies have shown that the use of such ostensive communicative cues can modulate infants' attention to (7), interpretation of (41), and subsequent imitation (42) of adults' behaviour. Moreover, much evidence suggests that learning in a social context is beneficial for learning beyond the information exploitation that social contexts permit. For example, the presence of a responsive social partner has been shown to be crucial in infants' language learning (43, 44), supporting the proposal that social contexts create increased arousal in infants and young children, and that arousal is likely to be beneficial for learning (45). Consistent with this, our finding that the amplitude of theta oscillations (in the temporal recording site) increased from baseline in anticipation of information in both conditions (Informant and Non-Informant) suggests that infants in this study were motivated to learn from both social partners. However, while the social context of the current study may have elicited general heightened arousal in infants, our data demonstrates that even when all information is conveyed socially and ostensively, infants nevertheless discriminated between experimenters, and selectively prepared to encode information from the optimal source to a larger extent, supporting the proposal that infants actively participate in the cultural



transmission of knowledge (46). Finally, while previous studies have shown infants in the first year are able to allocate their attention (47) and guide their exploration (48) in a way that ensures maximal information gain also in non-social contexts, further research is necessary to explore whether the same mechanisms guide infant information seeking in both social and non-social situations.

The idea of the infant as an active learner and gatherer of information is not new. For example, from early in the second year of life, research has shown that infants are already evaluating the informative potential of a social partner and choosing to interact less with someone who has shown themselves to be unreliable, unknowledgeable, or lacking informative potential (10, 29, 30). In the current study, we provide the first evidence that this same drive for information is likely to underlie infants' demonstrated preference to interact with others speaking the infants' native language. Thus, while heightened valuation of same-group members may have its origins in infancy, the origins of this preference may be a consequence of infants' drive to seek information from the optimal informant.

## **Materials and Methods**

### **Participants**

Forty-five 11-month-olds (19 female, age range 314-352 days) participated in the study and were assigned to one of 3 experiments. All infants, who took part in Study 2 (Native/Foreign), were monolingual, English-only hearing infants. An additional 24 infants were tested but excluded from analysis because they did not contribute the minimum number of 10 trials per condition required (due to movement artefacts or fussiness).

All participants were recruited from a database of infants whose parents had volunteered to participate in infant studies at the Centre for Brain and Cognitive Development, Birkbeck College, University of London. Written informed consent was obtained from the infants' caregiver before the experiment was conducted. The procedure was approved by the ethics committee of the Department of Psychological Sciences, Birkbeck College, University of London.

### **Procedure and stimuli**

Infants were sat in a high chair, in a darkened room, in front of 102cm (width) x 58 cm (height) plasma screen. The accompanying caregiver was sat behind the infant and instructed not to interact with their infant. The stimuli were created using Apple Final Cut Pro and presented with MATLAB (The MathWorks, Natick, MA) using the Psychophysics Toolbox extension. Stimuli consisted of a *Familiarization phase* (6 trials), followed by a *Test phase* (maximum of 48 trials, 24 trials per condition, minimum 10 valid trials per condition required to be included in the final sample, number of trials

contributed per condition (averaged across Experiments): Informant ( $N = 12.45$ ,  $SD = 2.99$ ), Non-Informant ( $N = 12.29$ ,  $SD = 2.77$ ). Order of trials within *Familiarization* and *Test phase* were randomised, and the role of experimenters (Informant or Non-informant) in the videos was counterbalanced across infants. Video recordings of infants during the session were used to exclude any trials in which the infant was not attending.

*Familiarization phase.* Two female experimenters, Informant and Non-Informant, were presented side by side with objects placed in the middle of a table in front of them. The experimenters were dressed in different clothing (green and red t-shirts) and remained in the same position (left or right of the object) throughout the entire experiment to aid infants' discrimination between the two. Familiarisation videos consisted of the following sequence of events: *Direct gaze* (1 second), in which both experimenters faced the infant, smiled and shifted gaze to the object; *Anticipation 1* (2 seconds), during which both experimenters were looking at the object without moving or speaking; *Outcome 1*, in which the first experimenter interacted with the object, while alternating gaze between the object and infant; *Anticipation 2* (2 seconds, identical to the first); and *Outcome 2*, in which the second experimenter interacted with the object, while alternating gaze between the object and infant. Which of the two experimenters, within a trial, acted on an object first was counterbalanced across the *Familiarisation* trials. Objects used in the *Familiarisation phase* were chosen amongst the most frequently known objects at 11 months of age (based on MacArthur-Bates Communicative Development Inventory, online data-repository, see S1).

*Test phase.* Each trial began with a 1-second long audio-visual animation in the centre of the screen, which served as the *Baseline*. Test videos presented only one of the two experimenters, sat in the same position as in the *Familiarisation phase*, and consisted of the following sequence of events: *Direct gaze* (1 second) in which the experimenter faced the infant, smiled and shifted gaze to the object; *Anticipation* (2 seconds), during which the experimenter looked at the object without moving or speaking; and *Outcome*, in which the experimenter interacted with the object, while alternating gaze between the object and infant. Duration of the *Outcome* periods were matched between conditions of each experiment (Informant, Non-Informant), but differed between experiments: Experiment 1 (3s); Experiment 2 (5s); Experiment 3 (3s) because Experiment 2 involved a demonstration of function. The content of the *Outcome* period differed according to the experiment.

**Study 1, Experiment 1, Label/ No Label:** The Informant pointed to the object and labelled it; Non-Informant pointed to the object and vocalised (“Oooh!”). The labels used to name familiar objects in the *Familiarisation phase* were object-appropriate (e.g. “That’s a duck!”). The labels used to name novel objects in the *Test phase* (Figure 2) were pseudo-words (i.e. nonsense words that obey the phonetic, prosodic, and phonotactic rules of a given language, e.g. “That’s a blicket!”), confirmed to be unknown to infants by the accompanying caregivers.

**Study 1, Experiment 2, Function/No Function:** The Informant pointed to the object, vocalised (“Oooh!”), picked it up and demonstrated its function; the Non-Informant pointed to the object, vocalised (“Oooh!”), picked it up and looked at it while turning it around in her hands. Functions demonstrated by the

Informant in the *Familiarisation phase* were conventional (e.g. drinking from a cup), but produced no effects. Functions demonstrated on novel objects in the *Test phase* were object-appropriate but likewise produced no effects (Figure 2).

**Study 2, Experiment 3, Native/Foreign:** In the *Familiarisation phase*, the experimenters labelled familiar objects. The Informant (native speaker) pointed to the object and labelled it in English (e.g. “*Look, a duck!*”); the Non-Informant (foreign speaker) pointed to the object and labelled it in Spanish (e.g. “*Mira, el pato!*”). Labels used to name novel objects in the *Test phase* were the same pseudo-words used in Experiment 1 and identical for both conditions (Informant and Non-Informant).

Objects used in the *Test phase* of all experiments were chosen as unlikely to be known to 11-month-old infants and confirmed as such for each infant by the accompanying caregivers. Details on objects used in the *Familiarisation* and *Test phase* of the experiments, as well as the corresponding labels and actions are described in Supporting Information online (S1 and S2).

### **EEG acquisition and analysis**

EEG was recorded using a 128-channel Geodesic Sensor Net (GSB; EGI Inc, Eugene, Oregon), with respect to the vertex electrode, at a sampling rate of 500Hz\*. Prior to analysis, the data was re-referenced to the average and high-pass filtered at 0.3Hz. The data was then segmented from 1000 ms before trial onset to 3400 ms following the onset, and visually screened for motion and blink artifacts. A continuous Morlet wavelet transform at 1 Hz intervals in the 1-50 Hz

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\* Due to a technical issue, 4 subjects in Experiment 3 (*Native – Foreign*) were recorded at a sampling rate of 250Hz. Because all the examined frequency bands were below 50Hz, the lower sampling rate does not affect the results.

range was performed on the artifact-free epochs. To eliminate distortion created by the wavelet transform, the first and last 400 ms of each epoch were removed. The data was baseline-subtracted (baseline period of 600ms before the beginning of *Direct gaze*) and average wavelet coefficients were calculated for each infant by taking the mean across trials. We analysed activity in the theta frequency band (3-5Hz) in clusters of electrodes over the frontal lobe (9, 14, 15, 21, 22, which approximate Fp1 and Fp2 in the 10-20 layout), bilateral temporal sites (left temporal: 45, 46, 50, 51, 58 (T3 and T5 in 10-20); right temporal: 96, 97, 101, 102, 108 (T4 and T6), bilateral central electrodes (left central: 7, 30, 31, 36, 37 (C1 and C3); right central: 80, 87, 104, 105, 106 (C2 and C4)) and a cluster of occipital electrodes (70, 71, 75, 76, 83 (O1 and O2)). Preliminary analysis revealed no differences between hemispheres (see SI, S3 Results), therefore the bilateral electrode clusters were pooled together creating four areas of interest: Frontal, Temporal, Central and Occipital.

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## Figure Legends

**Figure 1.** Stimuli still-frames with speech schematics representing the sequence of events in *Test Phase* trials: *Baseline*, *Direct Gaze*, *Anticipation*, and *Outcome* period, presented separately for Experiment 1, 2 and 3. Trial outlines are presented separately for Informant (top) and Non-Informant (bottom) conditions.

**Figure 2.** Summary of results. A) Time-frequency plots for average of all *Test phase* trials for each of the 3 Experiments. Amplitude of oscillations between 2 and 10Hz is presented separately for Informant (left) and Non-informant (right) conditions, of each Experiment. Red frames mark the time period and yellow frames mark the frequency range (3-5Hz), used for analyses. Data presented is the averaged activation across the marked electrode clusters in frontal (top) and temporal (bottom) recording sites, where significant modulations in amplitude of theta oscillations were found. B) Bar plots representing the average amplitudes of theta oscillations for the marked *Anticipation* period of each Experiment separately, and the average across all Experiments (Total). Significant activation compared to *Baseline* is represented with asterisks above bars; all tests were two-tailed; significance level was corrected for multiple comparisons within each Experiment ( $p < 0.0125$ ); error bars represent 1 SEM.