



Abstract Book – Symposia

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Symposium 1.1 - Role of motor development on infant perception

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Summary

Across four studies, we integrate multiple perspectives on the motor-perception link in infancy. Presenter 1 shows a real-time cascade linking infants' posture, visual access and caregiver language, highlighting the embodied nature of language development. Presenter 2 by disentangling motor from visual experience shows that limiting access to motor representations alters interpretation of others' grasping actions which in turn depends on infants' fine-motor skills. Presenter 3 shows that infants who practice pointing show increased frontal motor-visual connectivity when watching pointing actions as opposed to a non-intervention group. Presenter 4 demonstrates the link between early motor skills and perception as well as how neural maturity in sensorimotor brain areas significantly predicts gross motor skills in infants. The Discussant will contextualize above findings providing key insights into motor development, perceptual learning and neural mechanisms underlying infant perception.

Details

Abstract 1, Words with a view: Infant body position shapes opportunities for word learning:

Language learning is embodied—infants learn words as they learn to move. Indeed, infants regularly transition among multiple body positions; prone (e.g., crawling), sitting, and upright (e.g., standing). Different body positions influence what infants see (Figure 1A). While prone, infants' views are dominated by the floor in front of their hands. But when infants sit or are upright, the larger environment is visually accessible. Do changes in moment-to-moment body position influence opportunities for word learning?

We observed 20 infant-caregiver dyads (all 13-month-olds, half crawlers, half walkers) during $M = 9$ min (range = 4 to 17) of spontaneous play in a toy-filled lab playroom. Infants wore head-mounted eye trackers which recorded the focus of their visual attention. From video, we identified infant posture and caregiver naming events (i.e., when caregivers labeled a toy with a noun). Then we annotated the context of each naming event during a 6-s window (3 s before and after each noun). For each video frame, we identified whether infants fixated their gaze on the target toy (being named), a competitor toy, their caregiver, or away (i.e., other area of the room).

Time spent across body positions differed for walkers and crawlers (Figure 1B). Walkers spent most of their time in upright positions ($M = 62\%$), but crawlers preferred to sit ($M = 59\%$). In general, walkers heard more naming events than crawlers ($M_s = 2.9$ and 1.8 nouns/min, respectively; Figure 1C); however, this difference did not reach significance, $t = -1.67$, $p = .06$. Nonetheless, infant body position shaped the frequency of caregiver naming. More naming events occurred when infants were upright ($M = 2.7$ nouns/min) and sitting ($M = 2.0$ nouns/min) compared to prone ($M = 1.0$ noun/min; Figure 1C). The distribution of naming events across body positions differed for walkers



and crawlers. Walkers heard most nouns while upright ($M = 70\%$), and crawlers heard most while sitting ($M = 62\%$). Naming events were rare when infants were prone, regardless of locomotor status. Surprisingly, although sitting and upright positions showed an advantage for eliciting labels, infant gaze patterns to the target toy did not differ across body positions (Figure 1D). That is, when a naming event occurred, infants spent similar percentages of frames fixating their gaze to the target toy while upright ($M = 29\%$), sitting ($M = 34\%$), and prone ($M = 24\%$). Infants rarely looked at competitor toys ($M_s < 8\%$) or their caregiver ($M_s < 19\%$); rather, they mostly looked away ($M_s > 39\%$).

In sum, although infants received more instances of naming events when occupying postures that presumably offered them better views of the world, they spent similar amounts of time looking at target toys regardless of body position. In ongoing analyses, we will test whether toy location (e.g., infant's hand, caregiver's hand) and distance (i.e., within versus beyond infant reach) shape gaze patterns in each body position.

Abstract 2, Using a novel motor interference paradigm to investigate mechanisms for the perception-production link in infancy: There is an intriguing link between infants' motor development and their perception of other people's actions and goals. Multiple mechanisms for this relationship have been proposed. One proposed mechanism emphasizes the role of the motor system in self-other mapping, theorizing that the ability to perform a new action contributes to the ability to represent and interpret the same action when performed by others. However, at a more concrete, empirical level it has proven difficult to assess the effect of motor experience on action perception, because motor experience and visual experience are often confounded in infant development. With more time spent performing a manual action there is also an increase in the time infants have spent watching their own motor performance and seeing the outcome of their action. Consequently, correlations between motor experience and an outcome measure (e.g. looking-time to an event) could be due to the role of the motor system, to infants' increased visual experiences of seeing their own movements, or to the contribution of combined visuo-motor processes.

To examine whether motor processes are causally involved in infants' perception and understanding of action, we used an experimental intervention. This intervention was adapted from research with adults in which the ability to perform and consequently to represent a given action is inhibited by restricting the ability to move or use a relevant part of the body. In a within-subjects design, 48 12-month-olds watched adult reach-to-grasp actions under two conditions of hand posture in randomly-assigned order. In one condition their hands were free, and in the other, their hands constrained to block the formation of precision grips and other thumb-opposite grip shapes (Figure 1). We examined infants' looking time to two objects present during the adult action, one of which was congruent with the actor's reaching hand shape (precision vs. power grip shape), and the other was incongruent. A standardized parental questionnaire was used with each of the infants to assess individual differences in fine motor skills.

A multilevel, mixed-effects model was run with the outcome variable of relative preference for the congruent object, and factors of infant hand posture (free or constrained), adult actor grip type (shaped for power or precision grip), infant's fine motor score, and interactions between these (Table 1). Results showed that infant looking times significantly varied as a function of the interaction between infants' existing fine motor skill and their experimentally-manipulated access to motor representations of the action ($p = 0.017$). The better an infant's fine motor skills, the greater the reduction in their looking time to the actor's target (congruent) object during the hands constrained condition. The findings show that restricting concurrent access to a representation of



one's own body (by inhibiting the ability to perform a specific motor act) affects infants' perception of other people's related actions, but it does not do so independently of infants' existing motor skills and experience. Discussion will focus on the implications of these new findings on theories about the role of the motor system in action perception.

Abstract 3, Experience shapes functional connectivity during action observation in the first year of life:

Background: During the first year of life, infants undergo dramatic changes in their capacity to perform actions and to process others' actions. For instance, around 10- to 12-months infants become increasingly efficient in reaching and grasping and start producing communicative actions such as pointing. Importantly, accumulated experience with performing an action is connected to changes in perceiving the action. Moreover, intervention studies reveal that even short-term practice with a new action can alter how infants perceive the goal of the action. At the neural level, these changes are reflected in functional connectivity between motor and visual brain regions. Recent evidence indicates that infants exhibit heightened motor-visual connectivity when observing familiar actions, which scales with their level of action competence. However, it remains an open question whether experience and acquisition of a new action modulate motor-visual connectivity.

The period between 10 and 12 months is when infants are proficient in grasping but when pointing is emerging. Therefore, it is particularly well-suited to investigate whether the magnitude of motor-visual functional connectivity differs when infants observe actions they have more experience with, like grasping, versus actions with which they have relatively little experience, such as pointing. In the current study, we asked whether 10-to-12 months infants exhibit motor-visual connectivity during observation of grasping and pointing actions, and whether motor-visual connectivity during pointing varies with exposure to an intervention that supports the development of pointing.

Methods: We re-analyzed EEG data from Salo et al., (2023), which included a pointing intervention study designed to increase infants' exposure to pointing. In this prior study, 10-to 12-month-old infants participated in two lab visits one month apart, during which EEG was recorded while they observed pointing and grasping actions. Between visits, parents in the intervention group were encouraged to practice pointing with their infants daily, while those in the control group received no specific instruction regarding pointing (Figure 1). Functional connectivity was computed during infants' observation of grasping and pointing trials using inter-channel phase coherence, measuring the consistency of phase angle difference between two clusters of channels.

Results: We replicated previous findings of heightened motor-visual connectivity during the observation of others' grasping actions but did not observe differences during the observation of pointing actions. Moreover, motor-visual connectivity was not associated with pointing proficiency. To assess the connectivity pairs that may have changed as a function of pointing intervention experience at the whole-brain level, we explored the participants who provided data for both time points (Time 1 and Time 2). Notably, exploratory analyses revealed preliminary evidence of an increase in frontal-motor-visual connectivity during observation of pointing following the pointing intervention, with no such changes in the control group (Figure 2).

Conclusion: Together, these findings suggest that different stages of action competence are associated with distinct patterns of functional connectivity: established skills such as grasping may be associated with specialized motor-visual networks, while the early acquisition of new skills, like pointing, could be reflected by broader changes in connectivity across networks.

Abstract 4, Investigating the neural underpinnings of motor-perceptual development at infancy: Motor milestones in infancy, such as the transition from crawling to walking, have a



fundamental impact on how infants perceive and engage with their environment. Here we present a study testing the action-perception link in infants during this transitional period, when they were twelve-month-old ($n = 86$). Specifically, we investigated the relationship between early gross motor development and emerging perceptual skills, including spatial navigation and proprioception. Gross motor ability was assessed using tasks adapted from the Bayley Scales of Infant Development–III. Spatial navigation was measured with a parent-assisted hide-and-seek task, and proprioception was assessed using a “moving walls” paradigm implemented in a virtual reality (VR) setup. While these behavioral associations suggest a close link between motor and perceptual development, the neural mechanisms underlying early motor milestones remain unclear. To address this question, a subset of 41 infants participated in a resting-state (sleep) Magnetic Resonance Imaging (MRI) scan.

Early gross motor development significantly predicted spatial navigation ($r = .34$, $p < .001$) and proprioceptive behavior ($r = .32$, $p = .003$). Because small infant samples limit strong behavioral-neural inferences, we utilized a large-scale anatomical MRI data-set from the Baby Connectome Project (BCP). Specifically, we used 873 anatomical MRI datasets to construct normative infant brain charts capturing the period of transition from crawling to walking.

Regional brain volumes were normalized by intracranial volume (ICV) to account for overall brain growth and to characterize region-specific normative developmental trajectories. Focusing on sensorimotor regions in a smaller sample of infants aged 9 to 15 months, several neural maturity metrics were significantly associated with gross motor skills, including the sum of normalized residuals ($r = .20$, $p < .04$), an integrative score combining normalized residuals with the regional trajectory slope ($r = .22$, $p < .02$), and a predicted brain age measure ($r = .20$, $p < .03$). When combined into a latent neural maturity variable, these metrics significantly predicted gross motor skills ($b = .24$, $p < .02$). These associations were stronger when analyses were extended to the sensori-motor visual regions; sum of normalized residuals ($r = 0.25$, $p = .007$), integrative score ($r = 0.25$, $p = .008$) and predicted brain age measure ($r = 0.22$, $p = .03$). Upon combining into a latent variable, these metrics also strongly predicted gross motor skills ($b = 0.33$, $p = .01$). These brain age measures will be integrated with the analyses of our MRI sample ($N = 41$), and we will present results with regards to the hypothesis that neural development (as explained by our neural maturity metrics) mediates the close link between early motor and perceptual development. This work will provide a critical perspective on leveraging big data to inform inferences in smaller samples and advance our understanding of the neural foundations of early sensorimotor development.

Symposium 1.2 - Measuring bilingual language environments using long form recordings

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Summary

Most infants worldwide grow up in multilingual environments, where language input differs fundamentally in structure, variability, and interactional dynamics from that of monolinguals, for which most tools are optimised. This symposium highlights methodological challenges and solutions for capturing these unique properties using Long-Form Recordings. We will discuss: 1)



how system choice affects measurement accuracy; 2) how weighting automatic measures by language-relative exposure allows to better estimate language input and parent-child interaction; 3) the development of cross-linguistically valid metrics; and 4) the need for a unified approach to sampling, annotation and analysis for ecologically valid, comparable, and reliable assessments. Across diverse populations and methods, these talks will highlight why multilingual input requires dedicated methodological choices and will offer convergent solutions to accurately measure early multilingual input using long-form recordings.

Details

Abstract 1, Title: **Comparing LENA to VTC-ALICE: Measurement differences are larger in bilingual households**

Longform recordings have become a central method for studying infant language development, as they can unobtrusively record infants' naturalistic language environments and infant speech production (Casillas & Cristia, 2019). Over the last two decades, LENA has been a central method for data collection and automatic analysis of infant language input through daylong recordings (Gilkerson et al., 2017). However, LENA is not without limitations: the software is proprietary and costly, trained exclusively on American English, and limited by the exclusion of overlapping speech (Cristia et al., 2020). VTC-ALICE is a recently developed open- source alternative trained on diverse languages. Unlike LENA, it accommodates overlapping speech (Lavechin et al., 2020; Räsänen et al., 2021), which may render it more suitable for studying diverse language environments, including those of bilingual infants. We compare adult word count and adult speech duration estimates from LENA and VTC- ALICE, in a dataset of 113 USA families (72 Spanish-English bilingual, 41 English monolingual) with infants aged 3-26 months recorded over 2 full days (one recording per child per day; mean duration 12.6 hours, SD: 1.48 hours). We examine: (1) overall agreement between the two systems, (2) whether agreement differs between monolingual and bilingual households, (3) whether patterns vary by speaker gender, and (4) what factors might explain any observed discrepancies. Results from linear mixed effects models show that LENA consistently estimates lower word counts compared to VTC-ALICE, across all households (602 words/hour fewer, $p < .001$). Critically, however, this difference was significantly larger in bilingual households compared to monolingual households (162 words/hour interaction effect, $p = 0.021$). This pattern held across male and female adult speakers, with no significant three-way interaction ($p = .089$), indicating that the larger discrepancy in bilingual households is consistent regardless of speaker gender. We then examined overlapping speech segments, which are excluded by LENA but included by VTC-ALICE. In bilingual households, the duration difference between VTC-ALICE and LENA (mean = 8.11 min/hour) did not significantly differ from the overlapping speech duration (mean = 7.78 min/hour; $p = .380$), indicating that overlapping speech fully explains the measurement discrepancy. However, in monolingual households, which saw more overlapping speech per hour than bilingual households, the overlapping speech duration (mean = 8.67 min/hour) significantly exceeded the duration difference between VTC-ALICE and LENA (mean = 7.37 min/hour; $p = .011$). This suggests that overlapping speech is not the only factor affecting the word-count difference between VTC-ALICE and LENA; follow-up validation comparing both systems to human transcription is required. These findings highlight important methodological considerations for studying language input in diverse populations. The larger discrepancy between LENA and VTC-ALICE in bilingual households means that system choice may affect language input measurements: researcher using the LENA



automatic software estimates in Spanish-English USA samples and drawing comparisons to monolingual English samples may underestimate bilingual input, not necessarily due to true differences, but partly due to LENA excluding overlapping speech. Validation studies comparing both systems to human transcription are needed to establish best practices for research in bilingual or multilingual environments.

Abstract 2, Title: What predicts bilingual children's vocabularies? Using daylong recordings to examine the joint contributions of relative language exposure and conversational turns

Research with monolingual and bilingual families has examined the role of language input and caregiver-child interactions on infants' language development. However, research with these two populations has had substantially different foci. Studies with bilingual infants have focused largely on the role of language exposure, often relying on parent questionnaires, interviews, or diaries. In contrast, research with monolinguals has often focused on characteristics of caregiver-child interactions like parental responsiveness or turn-taking derived from audio or video recordings. To date, few studies have brought these perspectives and methodologies together to examine how language exposure and characteristics of caregiver-child interactions predict language outcomes in bilingual infants. Caregiver responsiveness, or feedback in response to children's cues, has been identified as one key way to foster infants' early language learning. One way of operationalising caregiver responsiveness is with the number of conversational turns during caregiver-child interactions, which indicate how frequently a caregiver responds to their infant's communicative attempts. However, the relationship between caregiver responsiveness and language development in multilingual families is understudied. Since multilingual caregivers may have different levels of proficiency in each language, caregiver responsiveness may relate differently to infants' development in each language.

This study investigates the joint contributions of caregiver conversational turns and relative exposure to each language on bilingual infants' vocabularies. Using data from a longitudinal study with English-Spanish bilingual toddlers ($n=30$, current analysis based on 14; mean age = 26 months), we asked:

- 1) Does relative exposure to English/Spanish predict children's English/Spanish vocabulary?
 - 2) Does the number of caregiver-child conversational turns in each language predict English/Spanish vocabulary over and above relative exposure?
 - 3) Does the relationship between relative exposure, conversational turns, and child vocabulary vary as a function of language (e.g., vocabulary in English or Spanish)?
- Relative language exposure was estimated via a parent interview using the Language Exposure Analysis Tool (LEAT). Parents also completed the English and Spanish versions of the MacArthur-Bates CDI to assess their child's vocabulary.

Lastly, families complete a daylong home recording using LENA. To estimate conversational turns in English and Spanish, we performed manual annotation of 5-minute segments (sampled every 30 minutes) from the daylong recordings. The number of LENA-estimated conversational turns in English/Spanish segments provide an estimate of the number of conversational turns in English/Spanish. Multiple regressions showed that, after controlling for overall Spanish exposure,



the number of conversational turns in Spanish during the daylong recording was a significant predictor of children's Spanish vocabulary (see Tables).

In contrast, when predicting English vocabulary, overall exposure to English was a stronger predictor than the number of English conversational turns. This suggests that parental responsiveness in parents' dominant language (in this case Spanish) is an important predictor of children's vocabulary development in the home language, while other factors may have a greater influence on their vocabulary development in English. These findings open a window to aspects of language in caregiver-child interactions that have been understudied as influences on bilingual vocabulary development. We will also discuss issues related to measurement of bilingual language experiences.

Abstract 3, Title: Syllables, not Words or Minutes: Using Syllables to Achieve Cross-Linguistic and Cross-Speaker Validity of Infant Language Input in Diverse Environments

Quantifying language input to infants in diverse environments requires measurement approaches that can compare across different languages and speakers. This talk argues that purely word- or time-based measures result in biased estimates and proposes a syllable-based technique. The problem with word- and time-based measures: Research quantifying multilingual language input to children often uses word-based measures, including LENA's automated counts. This tradition stems from classic studies (e.g. Hart & Risley 1995) which established word counts as the primary metric of language input. In the field of bilingual language development, Orena et al. (2019) examined dual language exposure in French-English infants using LENA's automated word counts. While acceptable for typologically similar languages like French and English, word-based measures become problematic when comparing different languages. For example, a single word in agglutinative Quechua can contain the grammatical information of an entire multi-word Spanish utterance. Alternatively, time-based measures confound speaker differences with input quantity: adults and children produce words at different rates, making it unclear whether differences in minutes of input reflect actual differences or speaking rate variation. Syllables as a cross-linguistically valid unit: We propose using syllables as the fundamental unit of language input. They offer three methodological advantages: (1) theory-neutrality, capturing prosodic units that infants are sensitive to without assuming adult-like lexical parsing from the speech stream, (2) language-neutrality, without morphological typology confounds, and (3) speaker-neutrality, allowing us to distinguish genuine input quantity from speaker characteristics. Methods: We illustrate this methodology using longform recordings from two communities: a Quechua-Spanish community in Bolivia (n=10 infants, M age=12 months) and a Spanish- English community in the U.S. (n=10 infants, M age=9 months). We coded 30-second randomly sampled clips for speaker (adult/other child), addressee (target child/other child/adult), and language. Speaker diarization and syllable detection models estimated the (1) raw number of syllables in each recording and (2) proportion of syllables by speaker and register (e.g. # of syllables from adult females or # of syllables of child directed speech). Hand-annotation of syllable counts from N=12 recordings demonstrated high model-human fidelity ($r=0.83$, $p<.001$; mean absolute error= 3.29 syllables). Results: Syllable-based measurement revealed patterns invisible to word- and time-based measures. Simulations accounting for different syllable-to-word ratios (Quechua: 3.0; Spanish: 2.6; English: 1.3) show word-based measures overestimate Spanish exposure by 7% at balanced bilingual input and 12%



at 75% Quechua input, meaning the bias worsens in communities with greater indigenous language use (Fig. 1A). Minute-based measures confound speaker characteristics with input quantity: because children speak more slowly than adults, word counts artificially inflate the proportion of peer input, making it appear that Bolivian infants receive less child-directed speech from adults than they actually do (Fig 2). Syllable measurement revealed infants actually heard more input from adults than other children. These findings demonstrate that syllable-based measures improve on word- and time-based measures for estimating multilingual exposure, providing estimates that more accurately represent infants' language exposure and avoid false disparities between different cultural settings.

Abstract 4, Title: Measuring Bilingual Language Input with LENA: Methodological Challenges and Possible Solutions

Measuring infants' everyday language input is central to understanding how context shapes early development. The Language Environment Analysis (LENA) system provides automated, scalable estimates of adult word counts (AWC), child vocalizations (CV), and conversational turns (CT), which have been shown to correlate robustly with later language outcomes across multiple languages and contexts. However, recent evidence points to several critical challenges related to LENA use in multilingual contexts. Specifically, since LENA is unable to differentiate and categorize the languages used in the recordings, its automatic counts implicitly treat bilingual infants as monolinguals, overlooking the greater input complexity and variability characteristic of bilingual environments. Crucially, bilingual contexts are not simply additive combinations of two monolingual ones: children often experience lower relative exposure to each language while receiving comparable or even greater absolute input overall. Moreover, bilingual interactions frequently involve language mixing, interlocutor-specific language use, and dynamic code-switching—complexities that raw LENA counts cannot capture. Here, we will present findings from a structured literature review of 25 studies that address these challenges by developing diverse methodological adaptations for analyzing bilingual language environments using the LENA algorithm. Specifically, we will (a) synthesize the advantages, limitations, and trade-offs of these approaches and consider how they might be combined to yield more ecologically valid estimates of bilingual input; (b) identify the most promising corrective strategies for sampling, annotation workflow organization, testing, and validation. Finally, we will (c) demonstrate the practical application of these strategies on a small sample of Spanish–Basque bilingual recordings (n=5) to provide a working example and assess feasibility, including estimates for time requirements and workload. We will discuss how combining automated LENA outputs with targeted manual corrections and complementary fine-grained measures (e.g., short manual transcriptions, parental questionnaires, interactional coding) appears to provide a flexible framework for estimating bilingual language exposure. Across studies, such hybrid approaches balance time and resource constraints with the need for detailed, contextually sensitive data, while remaining adaptable to diverse linguistic environments and analytic aims. By situating these methodological considerations within the broader ecological realities of bilingual households, our work proposes a working analytical pipeline that illustrates how LENA-based measures can be enhanced to capture the complexity of infants' linguistic environments. In doing so, we aim to contribute to a more unified methodological framework to guide future studies of bilingual infant language exposure across diverse contexts.



Symposium 1.3 - The role of other children in language development

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Summary

Peers play a vital role in children's development. As siblings, schoolmates, or caregivers, they provide the social interactions that shape how children use language on a daily basis. This symposium brings together researchers investigating peer input across a range of social and cultural ecologies: three North American settings (the home, the lab, and preschools) and three subsistence populations (Tsimane', Tselal, and Rossel). Integrating recent technological advances in audio and video recording with detailed manual annotation, these studies reveal substantial variability in children's linguistic environments. They demonstrate the adapted quality of children's conversational input and selectivity in seeking out peer interlocutors, as well as the effects of peers on redistributing caregiver attention from younger to older children. Collectively, we highlight the ubiquity of child-produced speech and encourage future research beyond adult-infant interactions.

Details

Abstract 1:

Title: The Role of Older Siblings on Infant Language Exposure

Infants' early language experiences unfold within rich social contexts that shape how and whom they learn from. Yet much of what is known about early language development has come from studies typically investigating the caregiver-dyad relationship. However, families themselves are highly dynamic systems, showing substantial variability in how communicative contexts unfold.

Within these contexts, research has emphasized the features of child-directed speech (CDS), that is, speech that is simplified, prosodically exaggerated, and semantically tuned to the child. However, CDS is not a universal feature of caregiving; many communities engage infants primarily through observation and overhearing rather than through direct address. Despite these differences, infants around the world reach similar linguistic milestones, suggesting that multiple pathways can support successful language learning. The present study investigates how family dynamics contribute to variation in their linguistic input. Specifically, we examined whether the presence of older siblings influences the quantity and type of language directed to and overheard by infants.

We analyzed 76 daylong home audio recordings from 26 American families with infants aged 6 to 12 months. From each recording, two hours of audio were randomly sampled in 30-second intervals and coded for both speaker and addressee. This approach allowed us to capture the diversity of everyday communicative contexts across families and to systematically examine how ubiquitous target child-directed speech is.



Results revealed substantial differences in infants' experience of language depending on sibling presence. Infants with older siblings heard roughly half as much speech directed to them as infants without siblings. Notably, this difference was driven entirely by moments when the sibling was physically present—when the sibling was absent, adults addressed the infant as frequently as in single-child households. Moreover, when all child-directed speech was combined (including speech addressed to either the infant or the sibling), there were no overall group differences, indicating that the total amount of child-centered language in the home was comparable across families. What differed instead was how that language was distributed among the children and the extent to which infants were directed speech versus overhearing others in conversations.

These findings highlight that even within a relatively homogeneous cultural sample of American families, infants' exposure to language varies substantially depending on family structure and the moment-to-moment social interactions in the home. Siblings introduce new conversational partners, shift caregiver attention, and create opportunities for overhearing that may nonetheless serve as valuable linguistic input. Thus, rather than conceptualizing CDS as the sole or optimal route to language learning, it is important to consider how infants' environments support learning through a range of contexts. By situating infants' early linguistic experiences within the broader family environment, it illustrates how the presence of an older sibling can intersect with caregiving structures to shape the nature of infants' language input. In doing so, it calls for broader methodological and theoretical frameworks that recognize the diversity of infants' developmental contexts, not just across families but within families as well, and the multiple pathways through which early language learning unfolds.

Abstract 2 :

Title: Speech to and around younger infants in play sessions with older siblings

Infants' language development is inherently tied to their linguistic input, but the majority of research investigating infants' input has focused on adult caregiver speech (e.g., LENA measuring only adult word counts), often in dyadic interactions. Around the world, children interact with other children, and thus, the focus on adult caregiver input does not fully capture the majority of children's experiences. While younger siblings are found to have slower language development, research exploring this finding has focused on how adult language input differs for younger vs. eldest children. However, siblings also provide language input. Here, we describe a novel corpus of triadic interactions, measure properties of language input to and around infants in the context of their older siblings, and explore whether demographic properties influence total and directed language input.

Data comes from the SIBS play session corpus, a corpus of 15-minute in-lab play sessions featuring target infants (9-15 months), older siblings (3-5 years), and parents, see Figure 1 for setup and provided toys, collected in North America. N=30 play sessions. RAs transcribed speech and tagged addressee.

Analyses and results. Sibling speech made up ~33% of speech during play sessions. Token counts



were higher from adults ($M=1033$, $SD=298$) than siblings ($M=504$, $SD=148$; $p<.001$). Overall language input, and language input from parents and siblings separately, were not predicted by infant age, sibling age, sibling's age difference (all $ps>.05$).

We tested who speech was directed to, comparing infant-directed speech (from parents and siblings) to overheard speech (from the perspective of the infant, sibling-directed speech from parents, and parent-directed speech from siblings). Parents' and siblings' speech was primarily overheard by infants. Specifically, only 25% of parental speech was infant-directed ($M=202$ tokens, $SD=129$), and 6% of sibling speech was infant-directed ($M=30$ tokens, $SD=32$). There was a significant interaction between parents' infant-directed speech and siblings' age difference ($p=.015$), such that with larger age differences, parents produced more infant-directed tokens and fewer sibling-directed tokens, see Figure 2. However, siblings' infant-directed and overheard speech did not differ as a function of age differences ($p=.56$).

Lastly, we looked at whether this speech varied in complexity, using age of acquisition (AoA). The AoA of words produced by parents did not differ in directed relative to overheard speech, while siblings produced earlier acquired words overall, and more so in infant-directed speech ($p=.046$). However, words' AoA did not interact with siblings' age difference for either parents or siblings (all $ps<.05$).

Together, these analyses highlight that while speech from other children is a frequent source of input for infants with older siblings, it is rarely infant-directed. However, parents produce more infant-directed speech when their children's age difference is larger (here, approximately 45 months) relative to smaller (here, approximately 22 months), suggesting that a larger age difference between siblings (in our study) may increase infant-directed speech to younger siblings. Lastly, initial analyses of the properties of this speech suggest that overheard and infant-directed speech may not differ in word-level complexity in triadic contexts. Ongoing analyses will link these experiences to language development.

Abstract 3

Title: Networks of Social Interaction at Preschool

Research on children's naturalistic language input and use has tended to focus on parent-child interaction, neglecting how children learn to talk amongst themselves without adult scaffolding. Yet these peer interactions may be especially revealing of children's agency in shaping their own linguistic environment. Unlike dyadic exchanges with caregivers, multi-party settings with peers require children to actively select partners: by choosing their conversational partners, they shape their language input and use. To investigate children's language in peer interactions, we recorded free play among 37 preschoolers in the midwest US using vest-mounted cameras across 12 sessions, yielding approximately 142 hours of video. We report two sets of analyses on a subset of this data (16 recordings).



Reliability of automated transcription. We find that Whisper achieves a somewhat accurate word error rate of 0.336, though it is considerably more accurate at transcribing adult speech (WER 0.162) than child speech (WER 0.407). It incorrectly includes many utterances that hand coders found to be unintelligible or distant background noise, transcribing nearly double the number of utterances humans approved. These findings emphasize the necessity of human correction for transcripts of noisy multiparty settings with child voices.

Dynamics of Classroom Interaction. To characterize the structure of children's interactions and variation in their language exposure, we divided each session into 30-second bouts; any two individuals who spoke within a bout were considered to have interacted in that bout. Children interacted with many partners over an hour-long play session (~15 on average) but did not divide their time evenly (Figure 1). Plotting the number of utterances children experienced from any given interlocutor by their rank, we find a power-law distribution, consistent with having a few preferred interactants and a long tail of passing exchanges (Figure 2). Strikingly, language exposure varied widely even within the same classroom, from ~13 to ~90 words per minute across children. The mean length of utterance a given child heard also varied widely, from 4 words per utterance to 10 words per utterance. These findings raise new questions about what drives children's selective choice of partners, and whether such preferences shape trajectories of language learning.

Abstract 4:

Title: When do children adapt their speech for younger listeners?: Findings from three subsistence communities

In many small-scale subsistence communities, toddlers receive substantial linguistic input not only from adults but also from other children. Prior research has shown that (i) other children are frequent conversational partners, (ii) child-directed speech (CDS) may be less common than in urban, industrialized societies, and yet (iii) children in these communities nonetheless reach typical developmental milestones on time. Together, these findings suggest that other children's input may play an important role in scaffolding early language acquisition.

In this study, we explore this possibility by examining whether speech produced by other children exhibits evidence of simplification. It has long been established that CDS is characterized by distinctive properties, most notably shorter and less syntactically complex utterances relative to adult-directed speech (ADS). Such simplification has been assumed to facilitate language processing and learning. Despite the potential importance of other children's input in contexts where children constitute a major source of linguistic exposure, little is known about its qualitative structure.

Here, we examine whether speech addressed to toddlers by both adults and other children shows evidence of simplification relative to speech addressed to adults, and whether such patterns generalize across cultural and ecological contexts.



We analyze naturalistic long-form recordings from three subsistence populations, including children learning Tzeltal (Southern Mexico), Tsimane' (Lowlands, Bolivia), and Yélî Dnye (Milne Bay, Papua New Guinea). The sample includes 46 children aged 2–36 months (median = 15 months), with an average of 54 transcribed utterances per child (11309 utterances in total). Each utterance was coded for speaker type (adult vs. other child) and addressee (target-child-directed speech; “TCDS” vs. adult-directed speech; “ADS”). Linguistic complexity was quantified at the utterance level using Mean Length of Utterance in words (MLUw). Not that we are currently validating this measure against morpheme-based utterance length (MLUm); preliminary analyses indicate a strong correlation between MLUw and MLUm ($r \approx .85$), with no systematic differences across speaker types.

Using negative binomial mixed-effects models, we find that addressee-related simplification is not universal. In the Tsimane' and Yélî Dnye datasets, both adults and other children produced significantly shorter MLUw when addressing toddlers compared to adults. In contrast, no MLUw differences for TCDS were observed in Tzeltal, not from adults nor other children (Figure 1, but see Elming et al., 2022). Notably, when simplification occurred, child-produced input to toddlers was comparable or even shorter than adult input, suggesting that other children provide linguistically simplified input that resembles core properties of CDS.

Together, these findings refine prevailing assumptions about child-directed speech by demonstrating that (i) simplification is not a cross-culturally universal feature of speech to young children, and (ii) other children's speech to infants closely mirrors the interactional patterns observed in adult speech within the same community. In contexts where adults produce simplified utterances when addressing toddlers, peers do so as well; where adults do not, peer speech likewise shows no evidence of simplification. These results underscore the importance of peer input as a structured and context-sensitive component of infants' linguistic environments, expanding theories of early language acquisition beyond caregiver-centric models.

Symposium 1.4 - Infant exploration as epistemic foraging

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Summary

Infants are epistemic foragers, actively seeking the information that drives their development. This symposium examines how they construct their learning environments across contexts: from decisions in controlled tasks and everyday exploration to patterns unfolding over days and the sociocultural systems that shape what they can discover.

One contribution shows infants regulating uncertainty like information foragers, deciding when to stay with or leave an informational patch. Another captures foraging in the wild, revealing that infants orient toward complex scenes and explore more variably as motor skills develop. A third



documents how repeated play builds structure over time, and a fourth highlights how objects, routines, and cultural practices shape infants' opportunities to forage.

Together, these show how information landscapes emerge from dynamic, nested, experience-dependent systems, offering a multi-scale account of how infants build the worlds that build their minds.

Details

Abstract 1, Title: How infants learn the value of information (and to forage for it)

According to predictive coding, infants are constantly generating predictions about the world and acting to reduce prediction errors. This occurs not just by passively updating internal models, but by actively sampling the environment. In this view, looking is a form of information foraging: infants must decide when to stay with a current “informational patch” and when to move on. We borrow Marginal Value Theorem (MVT) from the foraging literature, where rewards are typically extrinsic (e.g., food, money), and use it to formalise curiosity-driven, intrinsically motivated behaviour in infancy.

In Study 1, a large sample of 8-month-old infants ($N = 331$) watched semi-predictable sequences of visual stimuli while we recorded eye movements. Our key hypothesis was that if infants behave like optimal information foragers, they should leave a sequence when the instantaneous information gain falls below the long-run average information gain. We therefore compared an MVT-inspired model, which tracks both momentary and running-average information gain, against alternative accounts based on the Goldilocks effect (Kidd et al., 2012) and on local information gain (e.g., Poli et al., 2020). Model-comparison analyses showed that the MVT model provided the best quantitative fit to infants' look-away behaviour, suggesting that infants use a history-dependent policy that balances current and expected future information rather than simply reacting to local surprise.

These findings show that infants treat information like a reward: they keep looking as long as they are getting enough of it, and leave when the “informational payoff” drops. This motivates Study 2, in which we ask whether information and extrinsic rewards are evaluated by the same underlying system. One possibility is that infants are equipped early on with mechanisms that treat information as inherently rewarding; another is that they gradually learn that acquiring information is valuable because it improves their ability to predict and manage the world.

In Study 2, 8-month-old infants ($N = 45$) and adults ($N = 37$) completed a novel EEG/eye-tracking task involving learning about the locations of intrinsic (informational) and extrinsic rewards. We used pupillometry and EEG multivariate pattern analysis to probe whether these outcome types recruit similar value-related physiology and neural patterns. Behavioural data indicated learning about both kinds of contingencies in both age groups. However, preliminary neurophysiological



and pupillometric results suggest less overlap between intrinsic and extrinsic reward signals in infants than in adults, consistent with the idea that treating information as a reward is gradually constructed through early experience rather than being fully present from the outset.

Together, these findings characterise infants as active agents who regulate their own exposure to information and progressively learn how to value it. By formalising looking as information foraging and tracing the developing relationship between information and extrinsic reward, the work illustrates how predictive-coding approaches can illuminate the mechanisms through which infants construct their environments.

Abstract 2, Title: Infants as active explorers: motor burstiness and visual complexity in early development

Infants may do more than simply encounter visual complexity – they may actively seek it out. From the start of life, exploration and perception are tightly coupled: infants sample the world through the movements their bodies make possible. Each new motor skill—rolling, sitting, crawling, walking—opens a fresh vantage point and a new stream of visual information (Smith et al., 2018). Crawling channels gaze downward (Kretch et al., 2014), sitting rotates the body into a different visual plane (Soska, Robinson, & Adolph, 2015), and walking reveals expansive, object-rich environments (Karasik et al., 2012). With every motor milestone, infants gain not only new actions but new opportunities to select—and perhaps preferentially seek out—visually complex, information-rich scenes. This motivates two central questions: Do infants orient toward visual complexity? And how does the organisation of exploratory behaviour and visual input change as motor skills develop?

To investigate this, we recorded naturalistic, first-person visual scenes from 1- to 30-month-old children ($n=96$) using head-mounted cameras (1080p @ 50 fps) with 6-axis gyroscopes (Nikolov et al., 2024) and extended vertical fields of view. Each family contributed ~80 minutes of everyday experience, yielding an ecologically rich dataset of infants' self-generated visual worlds.

Because exploration spans fundamentally different behaviours, we quantified it using a holistic metric. How else can we meaningfully compare the saccadic exploration of a stationary infant with the roaming movements of a toddler? We indexed exploration using burstiness: clusters of high activity interspersed with inactivity, derived from optical flow and gyroscope data, capturing patterns from periodic to random to bursty. Two measures—the Burstiness Parameter and Fano Factor—characterised the temporal organisation and variability of exploration. Although burstiness does not measure how much infants explore or why, it reveals how exploration is structured over time, offering insight into underlying information-sampling strategies.



Visual complexity was modelled with a deep convolutional neural network trained on human complexity ratings (Nagle & Lavie, 2020), which outperforms feature-based approaches and closely aligns with human judgements ($r = .83$). Age-related change was analysed using generalized additive models.

Preliminary findings (first 54 participants) show that central regions of the visual field contain significantly higher complexity than peripheral regions (all, $p < .001$), consistent with infants selectively orienting toward visually rich scenes. The temporal organisation of exploration changes sharply from 1 month to the onset of walking (~10 months): exploratory activity becomes less extremely intermittent and more structured over time ($p < .001$), alongside corresponding changes in the variability of visual complexity infants experience ($p < .05$). Together, these shifts suggest increasingly sophisticated and diversified information sampling as infants' motor repertoire expands. After walking begins, these patterns plateau, consistent with a transition from locally constrained to more global modes of exploration.

Together, these findings position infants not as passive observers but as active architects of their developmental input – constructing visual worlds that become increasingly structured and informative as their motor skills expand. Updated results ($n=100$) and deeper analyses of information-theoretic metrics will be presented at ICIS.

Abstract 3, Title: Epistemic Foraging Across Days: How Infants Build Predictive Play Worlds

Young children actively gather information and build knowledge about the world by learning the predictive structures embedded in recurring daily routines (e.g. mealtime, bedtime, going to school, circle time, and play) (Fivush, 1984; Bauer, 2007). Real-world learning rarely occurs in isolated, one-off experiences; rather, it unfolds within repeated contexts in which children encounter the same objects, and activities day after day and learn to expect what goes with what. Here, we examine children creating their own context – how they explore, select, and build predictive event structures over multiple time scales—moment by moment and day by day during repeated episodes of naturalistic free play.

This study presents children's ($N= 42$, ages 11-24 mo) self-generate toy handling experiences during free play with a set of 25 toys in their own home environment over four days within a week. The play is recorded from the child's head-mounted cameras to capture first-person view. The recorded videos were segmented to 5 sec bins, in which we coded the toys the child handled, yielding time series of toys handled for each play episode. To unravel the predictive structures that emerged from children's self-generated play, we apply network graph measures showing the moment-to-moment transitions, their shifts from handling one toy to another during play, as well as their overall accumulated frequency distributions of each day's handling experiences.



The results demonstrate progressive information gain within each play episode and across repeated daily play episodes. Moment-by-moment analysis of shifts among toys revealed selective transitions among toys: children repeatedly shifted to a small set of ‘head’ toys more often than shifting to the rarely handled ‘tail’ toys ($F(1, 41) = 51.02, p < .001$). Across four days, connectivity increased for both head ($F(3, 69) = 29.94, p < .001$) and tail ($F(3, 69) = 32.24, p < .001$) toys, indicating a systematic growth by returns to head toys as well as shifts to tail toys. Over four days, these daily transitions accumulated into skewed frequency distributions of toy handling—gaining overall more experiences with head than tail toys ($F(1, 41) = 23.77, p < .001$). Children showed significant day-to-day increases in total handling experiences with both head toys ($F(3, 69) = 24.76, p < .001$) and tail toys ($F(3, 69) = 41.08, p < .001$).

Together, these results demonstrate that children don’t abandon what they have already played with; instead, they are revisiting the same ‘head’ toys adding more experiences to their anchor toys to progressively expand and discover new predictive relations with the ‘tail’ toys. This growth pattern suggests that children accumulate information moment by moment and day by day, about a consistent set of toys by building off of what they know, and thereby generating an increasingly predictable structure, and creating a more complete picture of their own play context.

Abstract 4, Title: The Social-Cultural Opportunity Filter of Infant Exploration & Learning

Infants’ social-cultural context functions as an ‘opportunity filter’: Infants can only play with the objects available to them; explore the spaces they are permitted to explore; and learn the words they hear. As such, parents channel learning by organizing the physical environment and interacting with their infants with specific objects, during specific activities, in specific ways. Cultural views and practices further frame learning opportunities. A cultural expectation that infants should be socialized into a world of literacy might be expressed by the presence of books at home and bookreading routines, just as a cultural expectation that infants should ‘pitch in and help’ might be expressed by involving infants in chores. In a series of studies, we highlight the social and cultural contexts of exploration opportunities using video tours of infants’ physical home environments and observations of home activities.

Study 1 showcases the cultural context of exploration. Videos of infants’ home environments in three urban cultures (South Korea, Hong Kong, the United States, $N=63$ one-two-year-olds) were annotated for every toy and book in infants’ homes, the precise objects with which infants engaged, and the objects that elicited mother engagement. Infants had 100s of toys on average, but types of toys differed by culture. For example, Hong Kong homes had child-designed spaces filled with ‘electronic panels’ that presented words in Cantonese, Mandarin, and English, reflecting values around multilingualism. Infants regularly visited the panels using touch pens to elicit object names. Furthermore, the affordances of specific toys in specific cultures shaped infants’ exploration and exposure to specific words.



Study 2 illustrates how activity context affects toddlers' play interactions and exposure to speech. Mother-toddler and father-toddler dyads from NYC families (N=55, 24–36 months) engaged in their 'favorite activity' during separate home visits. Dyads varied in their activity selection, with half being spatial (e.g., blocks, puzzles). Activity choice related to parents' use of spatial language, and twice as many father-toddler as mother-toddler pairs engaged in spatial activities.

Study 3 spotlights how types of social input affect exploration. From transcriptions and annotations of two-hour home observations (N=38, 1-2-year-olds), we compared effects of mothers' multimodal participation (e.g., gesturing to and naming objects of infant manipulation) versus unimodal or no participation on the duration and complexity of infant object interactions. Infants' object bouts were more complex and 7.5X longer when mothers provided multimodal input relative to unimodal/no input. Robustness checks confirmed that multimodal input functioned to prolong the duration of infants' object manipulation.

Study 3 extended the benefits of multimodal input to father-toddler pairs. During separate home visits, fathers and mothers played with their toddler with spatial toys. Micro-behavioral analyses revealed that infants were more likely to follow fathers' and mothers' multimodal input than unimodal input with spatial talk, gestures, and spatial actions.

Collectively, findings show that cultural context, types of objects, activity context, and forms of parental input are filters on infants' opportunities for exploration, the duration and complexity of exploration, and the behaviors infants produce when exploring.

Symposium 1.5 - Before Birth: The prenatal foundations of psychological development

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Summary

The prenatal period has remained largely absent from psychological theories of perceptual, cognitive, and social development. This is despite evidence that the uterus is a rich sensory environment and the human fetus has an array of capacities, ranging from auditory processing of language (Lecanuet et al., 1987; Zimmer et al., 1993) to preferences for face-like visual stimuli (Reid et al., 2017). This symposium presents converging research on the capacities and parameters of fetal visual, auditory, motor, attentional, and early social systems systems, while highlighting the methodological advances that make such investigations possible. Through so doing, the promise and complexity of taking an experimental approach to fetal development may be seen. Collectively, the findings discussed illustrate that fetal research is essential for our understanding



of the origins of human psychological development.

Details

Abstract 1, Title: Exploring anticipatory visual responding in the human fetus

Visual orienting practices during infancy are the building blocks for social processes including understanding facial expressions, eye contact and action perception (Johnson, et al., 2008). Our knowledge of fetal visual perception is rudimentary, including how the fetus engages with the visual world. The current study investigates the presence of anticipatory visual gaze in the fetus. Specifically, can fetuses use an auditory cue to anticipate the appearance of a light stimulus?

The final dataset includes 40 singleton fetuses between 33 and 36 weeks gestation ($M=239.5$, $SD:4.75$ days). 2D ultrasound was used to visualise the fetal lens and record fetal eye movements. A modified version of the Visual Expectation Paradigm was employed. Fetuses underwent six familiarisation trials where a 500Hz tone (anticipatory cue) was followed by a light stimulus (dot diode emitting at 650nm) presented to their temporal visual field. Following the familiarisation trials, the fetus was presented with six test trials with two conditions: Light Absent (LA) and Light Present (LP). In LA trials, the auditory cue was followed by no light stimulus presented. LP trials were an exact copy of the familiarisation trials. Eye movements are recorded in each condition with the view to measuring fetal visual engagement. We hypothesise that fetuses will demonstrate eye movements towards a specific location (in which no visual stimulus is present) when they hear an auditory cue that has been previously paired with a visual stimulus presented in that same location.

Results indicate that there were comparable numbers of eye movements in the light present (median:2.5, $SD: 3.146$) compared to the light absent condition (median: 3.5 $SD: 3.428$); Wilcoxon signed-rank test ($Z= -0.517$, $W=167.50$, $p= 0.611$) suggesting that fetuses can perform anticipatory gaze. Investigating anticipatory gaze illuminates how fetuses engage with the uterine environment. Understanding visual orienting in utero informs our understanding of perceptual processes and the foundations of higher-level cognitive functions that could have their origins in the prenatal period.

Abstract 2, Title: Revealing fetal and newborn sensory responses using optically pumped magnetometers (OPM-MEG)

Investigating the neural basis of fetal perceptual ability has traditionally relied on cryogenic magnetoencephalography (MEG), a technique suited to non-invasively measure fetal brain activity through the maternal womb. However, the widespread adoption of fetal MEG has been hindered by the high cost, logistical complexity, and scarcity of cryogenic systems suited to pregnant participants, which remain confined to a couple of specialized research laboratories worldwide.



In the present work, we adopted a cryogenic-free MEG system based on optically pumped magnetometers (OPM-MEG). OPM sensors are lightweight and wearable, making them an ideal candidate for a flexible and scalable MEG application with fetal and infant populations. The aim of this study was to demonstrate the possibility to record in utero and ex utero brain activity in response to sensory stimulation using a wearable OPM-MEG solution. The final dataset included a group of 21 pregnant participants in their late third trimester (M gestational age = 38.3 +/- 1.1 weeks). Participants were asked to come back when with their 1-month-old newborns (N = 14; M age = 32.6 days). A simple auditory paradigm consisting of 500 Hz pure tones (100 ms duration, variable stimulus onset asynchrony) was used at both timepoints. An adaptable abdominal belt equipped with OPM sensor holders was designed to record fetal brain activity. Sensor placement was tailored to the fetal head position assessed via ultrasound. Newborns underwent the same paradigm with on-scalp OPM-MEG. Results demonstrated that OPM-MEG can successfully detect auditory evoked responses already before birth, with fetal group-level signals peaking at 330 ms post-stimulus onset. Infant responses to auditory stimuli showed a latency decrease compared to the fetal ones in terms of magnetometers (M fetal = 275 ms, SD = 59 ms; M newborn = 238 ms, SD = 42 ms; $p = .04$, mixed paired/unpaired t-test), and similar temporal dynamics with virtual gradiometers.

The findings from the fetal and newborn OPM-MEG acquisitions establish the feasibility of this novel MEG approach to record brain responses to sensory stimuli already before birth. By enabling non-invasive and scalable studies across the prenatal and perinatal period, OPM-MEG holds a promise as a lifespan-compliant neuroimaging tool for tracking neural development.

Abstract 3, Title: Understanding Emerging Temperament Through Fetal Behaviour and Maternal Perception

Personality is often considered genetically driven. Traits show lifespan stability (e.g. Asendorpf & van Aken, 1991; Haan et al., 1986; Robins et al., 2001) and twin studies report that genetic factors account for roughly half of the variance in personality (e.g. Bouchard and Loehlin, 2001). However, interpretations of early signs of temperament as a reflection of innate predispositions, overlook environmental influence at a time of rapid brain development. Most neonatal research samples infants during the first month, whereby caregiving practices may already influence behaviour. Parent-led versus infant-led routines in the first month already show differences in caregiver-infant interactions, and infant behaviours (Winstanley and Gattis, 2013). These early infant behavioural differences can predict longer term social, attentional, and mood difficulties (Guerin et al., 1997; Schmid et al., 2014; Smarius et al., 2017). Thus, environmental influence likely begins earlier than many genetic accounts assume.

These influences may extend into the prenatal period as parents form temperament predictions during pregnancy that correlate with postnatal temperament, particularly in unadaptability and unpredictability constructs (Diener et al., 1995). Further, maternal environmental factors, such as anxiety, can predict later motivational tendencies in offspring (Oldani, 1997). This raises a key question: do prenatal environments shape early temperament directly, or do they shape parental perception, which then influences caregiving? Gagne et al. (2015) proposed a potential self-



fulfilling prophecy in personality development whereby parenting practice is influenced by perceptions of infant personality.

But what shapes parental perceptions? Individual fetal activity levels both show continuity across pre- and post-natal periods (Eaton & Saudino, 1992) and correlate with maternal predictions of infant temperament (DiPietro et al., 1996; Groome et al., 1999). Fetal activity and temperament have both shown sensitivity to environmental influence with fetuses of lower-SES mothers moving less vigorously and showing more difficult temperament (Conjero & Rueda, 2018; Pressman, 1998). Such findings challenge the assumption that early behavioural similarities in twins reflect genetics alone, highlighting an overlooked role of shared prenatal environments.

The present study examined how fetal activity, maternal stress, and gestational age (GA) relate to maternal predictions of infant temperament. Mothers completed a 30-minute fetal movement recording, the Perceived Stress Scale (PSS, Cohen, 1983), and an adapted version of Bates' (1979) Infant Characteristics Questionnaire. Preliminary analysis of 50 participants shows that fetal movement negatively predicts ratings on the "dullness" construct, $r(44) = -0.37$, $p = .011$, while GA positively predicts dullness, $r(37) = 0.37$, $p = 0.02$. PSS correlated with predicted unadaptability, $r(44) = 0.35$, $p = 0.02$. However, in partial correlations controlling for all predictors, only fetal movement remains significant, $r = -0.53$, $p = 0.001$. This indicates that movement provides a unique contribution to maternal predictions, independent of maternal stress and fetal maturation.

These findings suggest that fetal movement may serve as an early behavioural cue shaping parental expectations, or alternatively, may index emerging temperament prior to birth. Incorporating prenatal behaviour into theories of temperament challenges the field to reconsider whether early traits are genetic signatures, environmental products, or the beginnings of self-fulfilling pathways in personality development.

Symposium 1.6 - Infants' categorization in naturalistic conditions

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Summary

How do infants form categories in real life, where encounters with objects and labels are often ambiguous and messy? This symposium uses screen-based familiarization with realistically variable stimuli and naturalistic exploration to ask which factors play a role in infants' (12-24 months) categorization with and without labels, approaching the question from three different angles and complementary methods: Paper 1 uses gaze-contingent eye tracking to examine the nature of self-generated learning schedules, investigating whether 'bursty' temporal sequences lead to better learning. Paper 2 asks how sparse, naturally phonetically variable labels guide categorization. Paper 3 uses head-mounted eye-tracking to examine category learning during



dyadic exploration with vs. without labels. We will discuss the converging view of cognitive learning mechanisms available under naturalistic conditions, and how to bridge the gap between tightly controlled paradigms and real-life experiences.

Details

Abstract 1

Title: Evaluating the Role of Temporal Structure in Early Category Learning: The influence and active generation of clustered schedules in toddlerhood

Natural events rarely unfold at perfectly spaced intervals (spacing; Billman, 2011), nor do they occur just once and never again (massing; Vázquez et al., 2006). Similarly, children's real-life category learning often shows clustered temporal patterns. For example, a child's experience with "dogs" in the park can be highly uneven: on some outings they encounter many dogs in quick succession, on others none at all, creating short, intense bouts of category-relevant input separated by longer gaps. This temporal clustering can be quantified as burstiness (Goh & Barabási, 2008; Kim & Jo, 2016). While adult learning appears sensitive to specific degrees of burstiness within their timing schedules, much less is known about their impact and self-generation in early development. Recent observational work suggests that parents' clustered speech supports word learning in toddlers (Slone et al., 2022), but causal and mechanistic evidence remains scarce.

The present study addresses this gap using an eye-tracking paradigm with 12- to 16-month-old toddlers. In a passive condition, toddlers view four novel alien categories under experimentally controlled massed, spaced, and clustered presentation schedules, enabling within-subject comparisons in category learning. In an active condition, toddlers control which category exemplar appears next via gaze-contingent selection, thereby self-generating their own learning schedules (Altmann et al., 2025). Data collection is ongoing, with target analyses on a final sample of $N = 100$ toddlers (50 per condition) assessing category learning via a novelty preference task comparing in-category exemplars to similar but distinct out-category exemplars. Crucially, we quantify each child's learning schedule using measures of burstiness and hypothesize that clustered timing will promote superior category learning (H1), that children will self-generate schedules along a burstiness continuum (H2), and that there, as well, higher burstiness will predict greater learning efficacy (H3).

Preliminary, descriptive analyses on $n = 65$ young toddlers (age in months: $M=14.4$, $SD=1.8$; 51% female; 54% passive condition) reveal a marginal difference between number of viewed stimuli (passive: $M=30.3$, $SD=8.96$; active: $M=26.6$, $SD=7.14$; $t(62.69)=1.86$, $p=0.067$), with passively presented schedules producing a broadly balanced distribution of viewed exemplars across the four categories (of each ca. eight exemplars viewed). By contrast, under active choice we observed an effect of location on trigger frequency, $F(3, 107)=5.55$, $p = .001$, with toddlers preferentially



sampling upper (top right: $M=8.77$, $SD=0.82$; top left: $M=7.93$, $SD=2.10$) over lower (bottom right: $M=6.0$, $SD=3.15$; bottom left: $M=4.81$, $SD=2.75$) locations. Consequently, children engaged more strongly with a subset of categories and tended toward more massed sampling (less switching) within those preferred locations. These results indicate that self-directed exploration, in the context of category learning, may lead to more exploitative and skewed sampling patterns. Active choice may reduce the likelihood of learning equally well about all available categories, perhaps in favour of learning especially well about a subset of them.

Whether or not final analyses will indicate that clustered schedules confer learning advantages in early development, this research will inform how different temporal schedules shape category learning and how toddlers structure their own learning experiences.

Abstract 2

Title: Phonetic reduction and infants' language-driven object categorization

Consistent spoken-word labels can influence infants' categorization of objects. If infants hear the same label applied to each of a series of similar but distinct objects (e.g., different animals), they may recognize the objects as exemplars of the same category, but fail to do so if the objects receive unique labels or no labels (e.g., Waxman & Markow, 1995). Infants' everyday life is unlikely to feature uniformly labeled or unlabeled exemplars though: Instead, infants generally receive a mix of both. Recent work on how sparsely labeled contexts affect learning (LaTourrette & Waxman, 2019, 2022) shows that labeling even a few initial instances (the first 2 of 6) is sufficient to facilitate categorization, suggesting that infants might use everyday sparse labeling events to help with object categorization. However, everyday environments also feature messier speech than the hyper-clear, consistently highlighted verbal labels typically used in lab experiments ("Look, it's a MODI!"). Here, we investigated the effects of sparse labels on infants' categorization given more realistic speech, with pronunciations that are not acoustically identical nor reliably prosodically highlighted.

We tested 32 infants (18-24 months) in a variant of LaTourrette and Waxman (2022)'s category familiarization-novelty preference procedure (Fig1) using the same visual stimuli but new audio/conditions. During familiarization, infants saw 6 exemplars each of two continuous categories (novel creatures varying in color, body part size and shape, and proportions). In one condition ("Variable Highlighting"), the first exemplar received a prosodically highlighted label ("There's a FENDLE over here"), while the second exemplar received a non-highlighted label ("There's a fendle over here") in which the novel word was shorter in duration and had no pitch accent. The remaining exemplars were paired with a non-labeling phrase ("Look over here!"). In the other condition ("1-Label"), only the first exemplar was labeled, using a highlighted label ("There's a POSK over here"). Each infant participated in both conditions (interleaved), with the pairing of conditions, visual categories, novel words, and presentation order counterbalanced across participants. Infants' categorization (novelty preference) was tested in a silent test trial for each



category, measuring infants' looking time to two previously unseen stimuli: one from a novel category and one from the familiarization category.

Categorization performance in the "Variable Highlighting" condition was significantly above chance ($p=0.005$) and LaTourrette and Waxman's original "reversed" control condition ($p=0.045$) (Fig2). Thus, infants formed categories despite more naturally varied labels. While performance in the "1-Label" condition was not significantly above chance ($p=0.112$), it was also not significantly lower than the "Variable Highlighting" condition ($p=0.255$), leaving open questions about whether non-highlighted labels were crucial to infants' success in the "Variable Highlighting" condition, or whether a single (highlighted) label is sometimes sufficient to facilitate categorization. Regardless, these results offer new, more naturalistic support for infants' use of sparse labels as a categorization signal.

Overall, this work demonstrates an important first step toward examining verbal stimuli more typical of everyday speech in categorization experiments, and suggests a new avenue for future research investigating how infants use ordinary, variable speech to inform category learning.

Abstract 3

Title: Infant Learning in Context: The Role of Labels in Real-Life Category Formation

Infants form categories as early as 4 months (Eimas & Quinn, 1994), yet most evidence comes from familiarisation paradigms that poorly reflect real-world experience. In typical tasks, infants view a tightly controlled sequence of successive exemplar images (Mareschal & Quinn, 2001). Natural contexts provide richer, more variable exposure, with encounters differing in duration and spacing and interleaved with other events (e.g., seeing a bird on a windowsill, then another later in a park). While labels guide categorisation in familiarisation paradigms (Althaus & Westermann, 2016; Plunkett et al., 2008; Waxman & Markow, 1995), they may be even more crucial in real life, helping children link experiences across space and time.

Here, we examined the role of labels in naturalistic dyadic exploration. Caregivers with infants (12-14 months) in a carrier explored four naturalistic areas (2.5 min each), encountering four animal toys in each: two novel category exemplars and two out-of-category (OOC) distracters (see Figure 1). Half the caregivers (aim $N=40$; data collection ongoing) were given a novel label for the category ("geepee"), while the others (aim $N=40$) were asked not to use animal names. A head-mounted eye-tracker (Pupil Labs Neon) captured infants' egocentric view and gaze. Categorisation was then assessed using preferential looking with real objects on a stage with an occluder (Figure 1). A previously unseen geepee was shown next to an OOC object, either similar (trials 1-2) or dissimilar (trials 3-4) to the geepees in material / shape. We predicted successful learning only with labels and expected exemplar-looking during learning to correlate with test performance.



We used machine learning to automatically identify geepees and test stimuli in the infants' dynamic egocentric view. We fine-tuned a pre-trained object detection model, YOLO11x (Jocher & Qiu, 2024), to detect objects frame-by-frame (mAP50=0.98) and create rectangular AOIs. A custom pipeline integrated infant gaze with AOIs.

A preliminary analysis (N=27; Mage=416 days; SDage=21.3 days; 9 girls; 12 label condition) using a 2 (label vs. no-label condition) × 2 (similar vs. dissimilar trials) ANOVA revealed a significant main effect of similarity, with a greater proportion of looking to the OOC object for dissimilar (M=0.60, SD=0.21) than similar (M=0.40, SD=0.26) trials, $F(25)=5.89$, $p=.023$, others n.s. ($ps>.32$). One-sample t-tests indicated significant familiarity preference in similar trials ($t(26)=-2.12$, $p=.043$) and novelty preference in dissimilar trials ($t(26)=2.47$, $p=.021$). Exemplar-directed looking during learning did not predict test performance, $r(25)=-0.08$, $p=.701$.

These findings indicate that, irrespective of labelling, children formed a precise category. While familiarity to novelty preference switch may reflect context effects (finding geepees in an unexpected setting) or continued learning, the systematic preferences found with both test types show that infants clearly distinguished geepees from other stimuli. The full-sample analyses will investigate the temporal dynamics of exploration, clarifying how real-world interactions shape early category learning and the role of labelling in linking dispersed encounters. In sum, we observe successful categorisation in a naturalistic setting and set the foundation for a fine-grained analysis of rich dyadic experiences that will shed light on what factors matter for category learning in real life.

Symposium 1.7 - Infant temperament × caregiving: multilevel pathways to early psychopathology and resilience

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Summary

This symposium presents four longitudinal studies examining how infant temperament and caregiving interactively shape risk and resilience. Across diverse cohorts, studies test how temperamental traits—negative reactivity, surgency, and regulatory capacity—interact with parenting environments, including maternal sensitivity, attachment, and dyadic affective patterns, to predict socioemotional and neural outcomes such as anxiety, early psychopathology, and neural markers of emotion regulation. Using behavioral observations, parent reports, EEG, state-space modeling, and growth modeling, findings converge: high-quality caregiving buffers temperamental vulnerabilities, promoting adaptive trajectories, while less supportive caregiving can amplify risk. By integrating behavioral, neural, and relational perspectives across diverse



populations, the symposium elucidates mechanisms linking early caregiving to developmental outcomes and informs strategies to foster resilience in childhood.

Details

Abstract 1

Title: *Infant Temperament Reactivity and Early Maternal Sensitivity Interactively Shape Neural Responsivity to Deviance: Implications for Pathways to Anxiety*

Early temperamental traits—negative reactivity (NR) in infancy and behavioral inhibition (BI) in toddlerhood—are associated with risk for later anxiety, yet the neurodevelopmental mechanisms linking early temperamental risk to anxiety are not fully understood. One promising theoretical mechanism involves heightened bottom-up attentional processes, reflected in neural measures such as mismatch responses (MMR) during electroencephalogram (EEG). Elevated neural sensitivity to unexpected sensory change (i.e., more negative MMRs) may reinforce hypervigilance and avoidance, strengthening anxiety pathways. However, factors shaping the stability of MMRs in early development remain unclear. This study tested whether maternal sensitivity—defined as contingent, warm, prompt, and appropriate responsiveness to infant cues—moderates associations between early temperamental risk and MMRs, potentially buffering or amplifying risk.

Data were drawn from the longitudinal Temperament Over Time Study (TOTS; $N = 291$). At 4 months, NR was assessed using laboratory-based measures. At 9 months, mother–infant interactions were video-recorded during a home visit and coded for maternal sensitivity. At 9 and 36 months, a three-stimulus auditory oddball paradigm was administered during EEG sessions. Mean MMR amplitudes were computed for both time points. P3 amplitudes, indexing novelty-related neural responsivity, were extracted for sensitivity analyses. Moderation analyses examined whether maternal sensitivity moderated associations between NR and MMRs or P3 amplitudes.

Results indicated that NR and maternal sensitivity interacted to predict MMR responses at 36 months ($p = .028$). Johnson–Neyman analyses showed that higher NR was associated with more negative MMRs at 36 months only at lower—but not higher—levels of maternal sensitivity. No significant interactions emerged for MMRs at 9 months ($p = .82$) or for P3 amplitudes at either time point ($ps > .57$). No significant main effects of NR or maternal sensitivity on MMRs were observed.

Findings suggest that infants with higher temperamental risk at 4 months and lower sensitive caregiving at 9 months exhibit heightened bottom-up attentional responses to deviance in toddlerhood—patterns relevant to anxiety risk. Although heightened bottom-up attention is not inherently maladaptive, more negative MMRs have been implicated in anxiety-related models. Results highlight how caregiving context shapes when early temperamental risk becomes reflected in neural processing and may inform early interventions targeting caregiving behaviors and neural mechanisms (e.g., MMR).

Abstract 2



Title: *Feelings of Connection Moderate the Association Between Infant Temperament and Emerging Psychopathology*

Within the first months of life, variation in infant temperament—early emerging differences in emotional and behavioral disposition—is linked to vulnerability for later psychopathology. Temperamental surgency, characterized by impulsivity, approach, and positive affect, is associated with risk for externalizing problems. Yet caregiving relationships critically shape socioemotional outcomes. Maternal postnatal attachment, conceptualized as the emotional bond or tie of affection between mother and infant, supports children’s development across domains. Mothers reporting higher-quality attachment often respond more sensitively to infants’ needs, potentially buffering surgent infants from later risk.

This study examined whether maternal attachment moderates associations between infant temperamental surgency and later psychopathology. Mother–infant dyads (N = 106) participated in a longitudinal study of early experiences. At 6 months, mothers completed the Maternal Postnatal Attachment Scale (MPAS) and the Infant Behavior Questionnaire (IBQ-R Short). At 36 months, mothers completed the Child Behavior Checklist (CBCL). A generalized additive model (GAM) was used to test main and interactive associations of maternal attachment and infant surgency with later psychopathology symptoms.

Lower maternal attachment at 6 months predicted greater child psychopathology symptoms at 36 months ($b = -0.97$, 95% CI $[-1.88, -0.06]$, $p = .043$). Among mothers with higher attachment (above the 30th percentile), infant surgency was not significantly associated with later symptoms ($b = -0.18$, 95% CI $[-0.42, 0.05]$, $p = .129$). However, among mothers with lower attachment (≤ 30 th percentile), greater infant surgency predicted more symptoms ($b = 1.15$, 95% CI $[0.27, 2.02]$, $p = .014$).

Findings indicate that associations between infant surgency and later psychopathology depend on the quality of maternal attachment. High-quality attachment may buffer high-surgent infants from elevated risk. These results underscore the importance of early caregiving in shaping developmental trajectories and highlight the need for future work examining mechanisms linking early caregiving and temperament to socioemotional outcomes.

Abstract 3

Title: *Dyadic Mother–Infant Affective States and Delta–Beta Coupling: Understanding Infant Brain–Behavior Associations in the Proximal Context*

Delta–beta coupling, indexed by the correlation between delta and beta EEG power, may reflect dynamic crosstalk between limbic and cortical regions underlying emotion regulation. Stronger, positive coupling is associated with fearful temperament and childhood anxiety, positioning it as a potential biomarker of early psychopathology risk. Yet most work has focused on brain–behavior links without accounting for caregiver–infant interactional context.

While extreme caregiving adversity clearly affects infant brain development, normative variations in mother–infant interactions may also influence neural and socioemotional functioning. More



inconsistent or less positive interactions may compromise experience-expectant brain processes, including delta–beta coupling. Modeling dyadic patterns of interaction may better capture dynamic, mutually influenced states governing the infant brain “in context.”

In this study, repeated measures of infant EEG and temperament were combined with behavioral observations of mother–infant affective interactions modeled with State Space Grids (SSGs). Participants included a diverse sample ($N = 113$; 40% ethnic minority; 80% college graduate). Infant resting-state EEG and negative affect were assessed at 4, 8, 12, 18, and 24 months. At 8 months, mother–infant dyads completed a 5-minute play interaction coded second-by-second for affective states. SSG metrics included dyadic unpredictability (whole-grid entropy; higher values = more unpredictability) and attractor state (return time to adaptive mother–infant positive/neutral states; higher values = weaker attractor).

Growth models indicated increasing trajectories of infant negative affect; random intercepts and slopes were extracted and included with SSG metrics in multilevel models predicting delta–beta coupling trajectories at frontal and parietal sites. Return time was concurrently associated with frontal coupling at 8 months ($b = -0.044$, $SE = 0.002$, $p = .035$), suggesting that dyads with longer return times exhibited weaker infant frontal coupling. Additionally, unpredictability interacted with the negative affect intercept to predict frontal coupling trajectories ($b = -0.015$, $SE = 0.005$, $p = .001$). Regions-of-significance analyses indicated effects at both low and high levels of early negative affect, reflecting distinct coupling trajectories for these temperament groups.

Findings highlight the joint roles of infant temperament and dyadic affective dynamics in shaping neural trajectories, advancing understanding of early brain–behavior development within proximal caregiving contexts.

Abstract 4

Title: *Early Infant Temperament Changes as Predictors of Early Psychopathological Symptoms*

Individual differences in temperament are well-established predictors of later psychopathology. Temperament encompasses emotional and motor reactivity and attention-based regulation, shaped by biological and contextual factors. In infancy, temperament is typically organized into three factors—Surgency, Negative Emotionality, and Regulation/Orienting—which undergo rapid development across the first year. Although numerous studies link early temperament to later internalizing and externalizing behaviors, far fewer examine how *changes* in temperament trajectories contribute to emerging symptoms.

This study investigated how changes in temperament during infancy predict internalizing symptoms at age 2. We hypothesized that higher initial levels and increases in Negative Emotionality would predict separation anxiety, selective mutism, and specific phobias, whereas higher initial levels/increases in Surgency and Regulatory Capacity would be protective.

Participants were drawn from a larger NIMH-funded study of 199 mother–infant dyads recruited from multiple U.S. regions. Mothers completed the Infant Behavior Questionnaire–Revised (IBQ-R) bi-monthly from 6 to 18 months; the Preschool Aged Psychiatric Assessment was administered at



24 months. Due to planned missingness, infants contributed data at varying time points (e.g., $n = 131$ at 6 months; $n = 108$ at 24 months).

Three growth models were tested for each IBQ-R factor (linear, piecewise, quadratic). Negative Emotionality was best captured by a linear model; Regulatory Capacity by a piecewise model; and Surgency by a quadratic model, consistent with prior research. Covariates included infant sex, maternal age, gestational age, marital status, and child race.

The intercept of Negative Emotionality predicted later separation anxiety symptoms ($p < .001$), such that infants higher in Negative Emotionality at 6 months showed greater separation anxiety at 2 years, regardless of changes over time. Although other predictors approached significance, additional findings may emerge with a more complete sample.

Symposium 2.1 - Born to learn: new evidence in fetal and neonatal cognition

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Summary

Past work suggests that at and even before birth, humans possess both domain-general and domain-specific mechanisms allowing them to attune to, and learn from, their earliest experiences. This symposium presents new evidence detailing the operation of both types of mechanisms. Talks 1 and 2 examine the operation of domain-general learning processes, by describing how extremely young humans (both fetuses and newborns) adaptively respond to repeated stimuli during distinct states of sleep and wakefulness. Talks 3 and 4 demonstrate domain-specific patterns of attention and neural responsiveness in newborns, demonstrating that already within the first few days after birth, neonates selectively direct their attention toward various forms of communicative stimuli, including human speech and referential points. Together, these findings help to better elucidate the behavioral and neurocognitive mechanisms enabling humans to adaptively interact with their environments.

Details

Abstract 1

Mapping the parameters of fetal response to external stimuli

The human fetus has many psychological capacities before birth, including the ability to allocate attentional resources to information in the environment (Reid & Dunn, 2021). The fetus can respond to light and sound, but similar to newborns, fetal attentional abilities are limited. Some studies show that fetal attention to auditory stimuli declines over time due to habituation (Hepper & Leader, 1996). The capacity to sustain attention to an external stimulus during the third trimester is not known. This study aims to understand how fetal attention to environmental stimuli changes over time. We used 2D ultrasound to scan a total of 100 fetuses aged between 33- and 36-weeks of



gestation for a final sample of 62 fetuses following exclusions. During a 10-minute scan period, we presented the fetus with light and sound stimuli across one baseline period, an experimental manipulation featuring light stimuli, a second baseline period, and a second experimental manipulation. We observed eye and head movements across the entire experimental session. We compared actual fetal response frequencies to seven hypothesised attentional response profiles based on possible attention mechanisms and capacities. For example, “slow engagement” characterises the fetus as having a relatively tonic response pattern with a delayed response to stimuli across the experimental session. Using a process known as Dynamic Time Warping (Giorgino, 2009), we allocated each fetus to the response profile that best aligned with their actual response. A chi-square goodness-of-fit test showed that the number of fetuses that best fit into each response profile was not equal, $\chi^2(5, N = 62) = 47.94, p < .001$. Overall, the best fit response profiles were “habituation” ($n = 23$) and “no response” ($n = 23$), followed by “attention limited” ($n = 7$), indicating an initial response before no longer engaging with stimuli. These results suggest that the human fetus has a limited attention capacity with a significant minority of fetuses able to attend to visual stimuli for approximately three minutes. Future fetal research should take this limited fetal attention span into account when designing experimental paradigms. This study provides foundational insights into what might be considered typical fetal responses to light and sounds in utero. It may also help with a more clear profile for a sleep classification for a fetus, with almost one quarter of fetuses giving no behavioural response during baseline periods and experimental sessions, indicating no engagement with stimuli potentially as a result of being in a sleep state. Currently there is no consensus for classifying sleep in the fetus within the field.

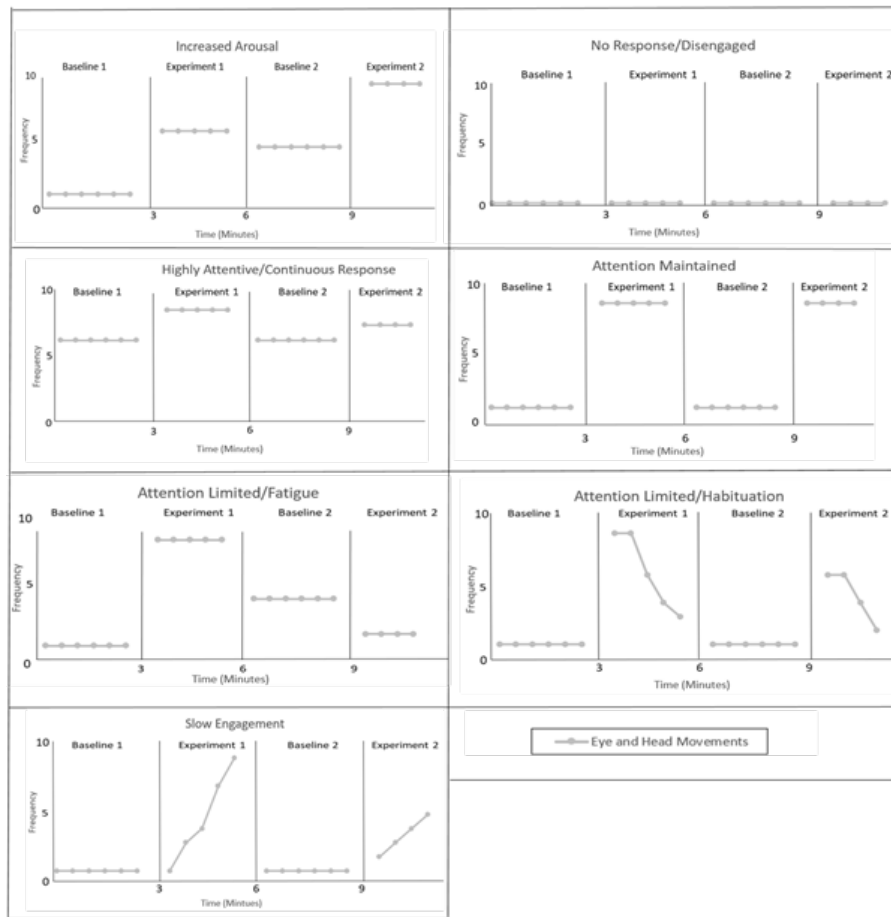


Figure 1: The seven hypothesised response profiles for the fetal sample across the experimental session.

Abstract 3: Neonatal Sleep and Learning: The Role of Sleep Stages in the Processing of Auditory Stimuli

Sleep is a major context in which early sensory processing and brain maturation occur. Newborns sleep about 70% of the time (Mirmiran et al., 2003; Tarullo et al., 2011), and during sleep they are able to process auditory stimuli to the extent that they can learn external auditory stimuli (Fifer et al., 2010; Benavides-Varela et al., 2011) or extract structural regularities from spoken language (Gervain et al., 2008; Flò et al., 2022). However, although early linguistic and memory abilities during sleep are well established, sleep's mediating role in learning processes still needs to be uncovered. This study explores how sleep state, active or quiet, affects habituation to auditory stimuli. Fifty-four healthy full-term newborns (2–5 days old; 37–41 GA; Apgar ≥ 8 ; complete hearing test screening) were assessed in a hospital setting using the Neonatal Behavioural Assessment Scale (NBAS, Brazelton, 1973). This involved repeatedly presenting a rattle stimulus with two independent scorers determining repetitions needed to reach habituation. Sleep state was determined through videosomnography, using the behavioural framework proposed by Grigg-Damberger (2017). Active sleep was marked by high motor activity, including body, facial, and eye



movements whereas quiet sleep was characterized by little to no movement except for occasional startles. Twelve participants were excluded from the analysis because they woke up ($n=4$), were awake during the assessment ($n=5$), did not habituate ($=1$), showed mixed sleep characteristics that did not clearly correspond to either active or quiet sleep (transitional sleep; $n=2$). Video coding classified seven newborns as showing active sleep and twenty-three quiet sleep. An independent samples t-test (one-tailed, $H_a: \mu_{\text{active}} > \mu_{\text{quiet}}$) showed that newborns in active sleep required a higher number of repetitions to habituate to an auditory stimulus ($M = 4.14$, $SD=1.86$, $SE = 0.705$) compared to those in quiet sleep ($M = 2.87$, $SD=1.10$, $SE = 0.229$; Figure-1). To account for the unequal distribution of these spontaneous behavioural states, a Welch's t-test was also implemented and confirmed the same pattern, $t(8.73) = 1.89$, $p = .047$. The results suggest that active and quiet sleep involve distinct information processing patterns at birth. During active sleep infants tend to continue responding to stimuli rather than progressively recognizing them as familiar, resulting in slower habituation. Although further studies are needed to confirm this pattern, one possibility is that the abundant spontaneous endogenous brain activity characteristic of active sleep (Blumberg et al., 2013; Shaffery et al., 2006) interferes with the ability to clearly distinguish new from repeated sensory input. On the other hand, during quiet sleep a lower number of repetitions, and thus faster adaptation, suggests its association with more efficient auditory processing. Quiet sleep, characterized by stable physiological activity, may offer a more "neurophysiologically quiet" environment that facilitates the encoding of external stimuli and therefore enables sensory information to be more efficiently processed. These results highlight the importance for future research to consider sleep architecture in neurocognitive development.

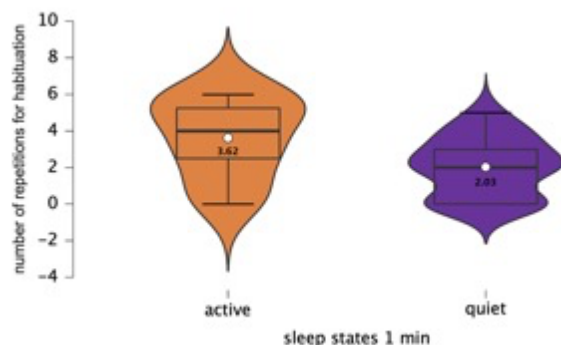


Figure-1. *Number of repetitions required to reach habituation criteria as a function of sleep state (Active or Quiet).* Colored violin plots show the distribution (kernel density estimate) of the number of repetitions. The horizontal thick line inside each violin plot shows the median value. The box plot around the median shows the interquartile range (IQR). The whiskers show the data range within $1.5 \times \text{IQR}$. The middle white dot indicates the mean value.

Abstract 3: What is speech for the newborn brain?

Human infants have sophisticated auditory and speech perception abilities already at birth. They prefer to listen to speech over synthetic sounds such as filtered speech (Spence & DeCasper 1987), backward speech (Peña et al. 2003), sine wave analogs (Vouloumanos & Werker 2004), white noise (Colombo & Bundi, 1981), and instrumental music (Glenn, Cunningham and Joyce,



1981). However, newborns show equal preference for both speech and monkey calls (Vouloumanos et al. 2010), leading to the idea that the category “speech” may not be fully specific at birth, potentially comprising primate vocalizations or communicative sounds in general. To test this idea, we have conducted four neuroimaging studies to assess whether newborns can discriminate speech from other communicative sounds produced by primate vocal tracts: (Exp1) monkey calls, (Exp2) newborn cries, (Exp3) infant and adult laughter, as well as (Exp4) song and humming. The first study recorded newborns’ brain responses in the speech and language areas, i.e. the bilateral temporal, parietal and frontal cortices, to speech, backward, i.e. time-reversed speech, monkey calls and backward monkey calls using NIRS-EEG co-recording (Figure 1A). NIRS revealed significantly greater responses to speech than to monkey calls in the right temporo-parietal areas (Figure 1B, blue ovals), while EEG showed that newborns can discriminate forward and backward stimuli in both conditions, but the mismatch response is more robust for speech than for monkey vocalizations. These results suggest that while newborns may prefer speech and monkey calls equally, they can nevertheless discriminate the two. The second study compared newborn responses to speech and newborn cries, a vocalization they themselves produce and that caregivers interpret communicatively. Using NIRS (Figure 1C), we observed greater activation to cries than to speech in right temporal regions (Figure 1B, brown oval). Adults who did not understand the speech stimuli showed the opposite pattern, i.e. greater activation to speech, suggesting that the newborn preference for cries cannot be explained solely by the acoustic properties or emotional valence of cries. The third study tested newborn discrimination of speech versus infant and adult laughter. NIRS responses were highest for adult laughter, intermediate for infant laughter, and weakest for speech, again indicating category discrimination (Figure 1B, teal oval). In the fourth study, we compared responses to speech, song, and hummed melodies. NIRS showed similar activation to speech and song, both greater than activation to humming in right parietal areas (Figure 1B, violet ovals), suggesting that newborns are sensitive to the linguistic component of song, which may thus scaffold speech perception and language acquisition. Across all four studies, newborn infants demonstrate specific and robust sensitivity to speech in a right temporo-parietal network, readily distinguishing it from a wide range of communicative sounds produced by human infants, adults, and nonhuman primates.

Abstract 4: Newborns’ sensitivity to pointing gestures

Recognizing that certain acts are communicative is necessary for the development of communicative skills. Consistently with theories of the evolution of ostensive-inferential communication (Grice, 1957; Sperber & Wilson, 2002), newborn infants have been shown to selectively respond to certain ostensive cues, including direct gaze and infant directed speech. Are they also sensitive to pointing gestures? According to a prominent proposal, infants’ understanding of pointing is thought to be linked to their embodied experiences derived from the generation of pointing gestures (Brune & Woodward, 2007; Gerson & Woodward, 2014). Since this ability to produce pointing emerges at around 10-12 months (Bates et al., 1975), we should not expect younger infants and neonates to be sensitive to the communicative value of pointing. However, no previous study has yet examined newborns’ responses to pointing gestures and assessed their sensitivity to the ostensive value of pointing. In the 4 experiments (N=90) reported here, we investigated whether a sensitivity to pointing is present in 5-day-old newborns. In all experiments we compared newborns’ attention to a canonical pointing gesture versus a fist via a preferential looking paradigm. Also, we manipulated several key factors that are cues to the communicative nature of the stimulus actions: (a) the presence versus absence of a referred-to target



(Experiments 1 and 2), (b) whether the pointing entity was an agent (a pointing hand) or an inert object (a pointing arrow; Experiment 3), and (c) whether the pointing hand was moving toward the target object or away from it (Experiment 4).

Results showed that newborns in Experiment 1 looked longer at a pointing hand than at a non-pointing fist, but only in the presence of a target object. This effect was replicated in Experiment 2. In contrast, newborns in Experiment 3 showed no visual preference for an arrow over a disc when each moved toward a target. Moreover, in Experiment 4, they showed no preference for a pointing over a non-pointing hand when each moved away from a target. Together, these results are the first to suggest that newborn infants are sensitive to a key communicative gesture, pointing. Crucially, their responses appear to be specific to points that are both social (i.e., human hands) and communicative (i.e., referential). We argue that these findings help to rule out accounts based on embodied experiences and that they cannot be accounted for by a general ability to detect goal-directedness in human actions. We propose that they reveal the existence of an experience-independent sensitivity to pointing as an ostensive signal, thus providing further support for theories positing that ostensive-inferential communication rests on domain-specific evolved adaptations.

Symposium 2.2 - How infants decide to persist: understanding motivational drivers in early problem solving

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Summary

When infants engage in problem solving, what drives their decision to persist? This symposium brings together three perspectives on the motivational drivers that support early persistence. Talk 1 shows that priming infants to explore multiple strategies increases their persistence by reinforcing the belief that success remains possible. Talk 2 demonstrates that infants persist longer and show increased pupil dilation when outcomes are uncertain, indicating that uncertainty motivates continued information seeking. Talk 3 reveals developmental changes in how infants use social information and their own experiences of failure to infer a task's solvability and guide their subsequent motivation. The discussant will integrate and synthesize these talks and highlight new directions in motivational drivers in infancy. Together, these talks identify exploration, uncertainty, and social-experimental cues as early motivational drivers that support persistence during problem solving.

Details

Abstract 1, Title: Priming exploration increases infants' persistence

Abstract 1, Title: Priming exploration increases infants' persistence



Infants frequently encounter challenges in their everyday lives that require persistence, such as retrieving objects, navigating barriers, and uncovering hidden objects. However, encountering repeated failure can be frustrating and can diminish motivation to persist. One potential way to overcome this frustration is through exploration, as success may be possible with novel strategies, even if previous attempts have failed. To investigate whether exploration enhances persistence, we conducted both a correlational and an experimental study examining infants' problem-solving and persistence behaviors.

In Study 1, we analyzed archival data from 96 infants (MAGE = 18.5) performing a means-end task which, unbeknownst to infants, was impossible to solve. Infants' actions in the beginning of test trials were classified as either imitative, exploratory, or off-task. When controlling for differences in infants' activity level, analyses revealed the proportion of time infants spent exploring in the beginning of trials, $\beta = 0.53$, $t(282) = 2.56$, $p = 0.01$, as well as the number of unique exploratory strategies, $\beta = 0.92$, $t(210) = 2.79$, $p = .005$, each predicted overall persistence on the task. Importantly, increased exploration also predicted increased persistence on a novel task, $r(68) = -0.33$, $p = .005$. As such, Experiment 1 provided evidence that infants' exploration to seek new solutions related to sustained efforts in the face of repeated failures.

Building on this correlational evidence, Study 2 experimentally tested the causal role of exploration in promoting persistence. Infants aged 18-24 months ($N = 60$, MAGE = 21.04 months) were assigned to either the Explore or No Explore condition through a priming task designed to shape their problem-solving approach. In the Explore condition, infants were encouraged to persist by trying different strategies after failure, whereas in the No Explore condition, infants were encouraged to persist by repeating the same strategy after failure. Following the priming task, infants in both conditions completed a separate task to measure persistence.

Infants in the Explore condition persisted more than those in the No Explore condition on the separate task, $\beta = 15.07$, $t(58) = 4.28$, $p < .001$, and this effect was mediated by their increased use of unique, problem-solving strategies, $ab = 13.30$, $SE = 1.75$, 95% CI [9.82, 16.69]. Importantly, infants in the Explore condition spent more time engaged in each bout of trying, $\beta = 9.49$, $SE = 2.63$, $t(58) = 3.62$, $p < .001$, indicating that their greater persistence reflected sustained problem-solving attempts rather than many shallow actions. Thus, infants in the Explore condition persisted longer because their exploration involved both a greater variety of strategies and more sustained attempts.

By examining both correlational and experimental evidence, we demonstrated that exploration significantly enhances infants' persistence when faced with difficult tasks. These results highlight the causal role of exploration in shaping infants' persistence, supporting the idea that engaging in varied problem-solving strategies fosters sustained effort, as it reinforces belief that success is possible.

Abstract 2, Title: Toddlers' Persistence in Information Seeking is Uncertainty-driven: A Pupillometry Study



Curiosity—intrinsically motivated information seeking—is a fundamental driver of exploration and learning. According to contemporary accounts such as the information-gap theory, curiosity arises from the urge to close perceived gaps in knowledge and reduce uncertainty. Recently, it has been suggested that preschoolers' persistence in information seeking is driven by uncertainty. Much less is known, however, about the early emergence and the psychophysiological mechanisms of uncertainty-driven information seeking.

This study investigated whether infants' information seeking is a function of outcome uncertainty. Using a gaze-contingent eye-tracking task adapted from Ruggeri et al. (2023), infants aged 13 to 21 months were presented with objects varying in uncertainty and tasked to find the object hiding behind one of a virtually infinite series of closed doors. In the High uncertainty condition, the objects were different from each other. In the Low uncertainty condition, all objects were identical, with the specific object identity randomly assigned to each toddler from the stimulus set.

If infants' information seeking is driven by the degree of uncertainty, we would expect their persistence in seeking out the object, reflected by the number of doors they looked through and their looking time, to be longer when uncertainty was higher. We further measured infants' pupil sizes during the presentation of closed doors as a physiological marker of uncertainty (Satterthwaite et al., 2007; Lavín, San Martín, & Rosales Jubal, 2014). We predicted infants' pupils would dilate under high uncertainty as a physiological response to outcome uncertainty. We also predicted pupil diameter reduction over time due to repeated exposure to the stimuli, consistent with habituation effects (Marois & Vachon, 2018; Snowden et al., 2016). We hypothesized that infants between 13 and 21 months begin to exhibit uncertainty-induced information seeking, reflecting an early emerging sensitivity to outcome uncertainty. This age range is critical because relevant work shows that during the second year of life, infants start to demonstrate metacognitive awareness capabilities and primitive metacognitive behaviors, such as adapting exploratory behaviors to the information structure of the task, hesitation and information seeking in uncertain situations, which predict more explicit uncertainty monitoring in preschool years (Lucca, Horton, & Sommerville, 2020; Li, Poli, & Ruggeri, 2025; Poli et al., 2024; Ruggeri et al., 2023; Leckey, Gonzales, Selmeczy, & Ghatti, 2025).

Evidence from infants' persistence in information seeking, reflected by the number of doors they looked through and their looking time, and pupil diameter changes converge to indicate that infants from 18 months of age persisted longer in seeking information under high uncertainty, and their pupil sizes increased when the uncertainty was high but decreased when the uncertainty was low. These findings suggest that the degree of uncertainty drives infants' persistence in information seeking, and this uncertainty-induced information seeking is accompanied by an increase of pupil size, revealing the early development and psychophysiological mechanisms of uncertainty-induced information seeking.

Abstract 3, Title: Developmental changes in infants' rational deployment of effort

Achieving success not only involves sustaining effort but also evaluating past experiences and likelihood of success to decide whether and how to persist. Prior research shows even infants weigh these factors to guide their persistence (Leonard et al., 2022; Lucca et al., 2020). In Lucca et al. (2020), 18-month-old infants watched an experimenter retrieve a toy by pulling a rope



connected to an out-of-reach box: infants learned that the task was either easy, difficult, or impossible to solve via the adult demonstration. Infants were then presented with the task, which unbeknownst to infants, was unsolvable. Findings indicated that infants used adult demonstration to form initial expectations of the task, that were adjusted based on their experience, affecting their trying time and pulling force.

To explore the onset of this integration, we administered Lucca et al.'s (2020) rope-pulling paradigm with 12-month-olds ($N=96$; $Mage=12$ months, 4 days). We found that infants' trying time declined across trials, $t=-3.78$, $p<.001$, however, there were no significant effect of adult demonstration, all $ps>.22$. However, these results may reflect differences in task skill rather than age-related differences given that 12-month-old infants struggle to solve multi-step means-end tasks.

Thus, in Experiment 2, infants received a more familiar task: directly pulling the toy off a table. Ten- to 14-month-old infants ($N=192$; $Mage=11$ months, 27 days) observed an experimenter easily retrieve the toy (Easy Condition), struggle before retrieval (Hard Condition), or unable to retrieve the toy (Impossible Condition). Infants then attempted an impossible version of the task (unbeknownst to them), where the toy was glued to the table. This sequence was repeated three times. To capture infants' persistence, we measured infants' trying time, pulling force, and their use of strategies. Finally, to measure infants' subsequent motivation in a similar task, infants completed a 'recovery trial' in which they were given a similar toy that was now retrievable.

If 12-month-olds rationally deploy effort, there should be an interaction between trial and condition similar to Lucca et al.'s (2020) findings. Alternatively, if the ability to integrate information is still developing, we may only observe a main effect of trial. Results showed that infants' trying time, $t=-11.40$, $p<.001$, and pulling force, $t=7.60$, $p<.001$, declined across trials, but did not significantly vary across conditions, both $ps\geq.12$. However, preliminary analyses on ongoing coding suggests that infants engage in fewer strategies across trials, $t=-6.23$, $p<.001$, and in Hard compared to Easy Condition, $t=-2.01$, $p=.045$. Importantly, in the recovery trial, infants in the Impossible Condition required more support from the experimenter to retrieve the toy, than in Easy ($t=3.17$, $p=.002$) and Hard conditions ($t=2.19$, $p=.029$).

These findings suggest that 12-month-old infants use some information from social input, particularly whether success is possible, but this only guides their subsequent motivation rather than their actual trying. Unlike 18-month-olds, 12-month-olds do not appear to adjust their trying based on observed difficulty, however, they engage in fewer strategies when the task appears to be difficult than easy. Together, infants' ability to uniformly integrate social input and their first-hand experience may rely on more advanced cognitive control and self-regulation skills that emerge later in infancy.

Symposium 2.3 - Early caregiving influences on child socioemotional development: evidence from diverse Latin American contexts

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Summary

This symposium brings together three studies from diverse Latin American contexts to examine which early caregiving processes most strongly shape socioemotional and cognitive development in the first three years of life. Study 1 shows that early cognitive stimulation uniquely predicts socioemotional adjustment at 12 months. Study 2 highlights father–child relationship quality—rather than involvement—as a central pathway for socioemotional competence. Study 3 demonstrates that maternal parenting beliefs, particularly hostility and overprotection, predict behavioral difficulties at 36 months, with modest cognitive effects. Together, these studies show that early caregiving dimensions—stimulation, relational quality, and parental beliefs—are stronger predictors of socioemotional development than structural or demographic factors, expanding evidence from underrepresented settings and identifying culturally relevant levers for early intervention.

Details

Study 1: Rethinking Early Learning Inputs: Why Stimulation Matters for Socioemotional Adjustment at 12 Months

Background. Early socioemotional development (SED) occurs during a period of heightened neuroplasticity, when infants depend on caregivers for external regulation and the scaffolding of emerging affective, communicative, and behavioral skills. While home learning environments predict cognitive and socioemotional outcomes, less is known about how specific early learning inputs—such as cognitive stimulation, learning materials, and structured experiences—contribute during infancy, or whether their effects vary by maternal postpartum depression or child sex. Clarifying which dimensions of early learning matter most in the first year is essential for guiding interventions that support adaptive socioemotional development.

Methods. This study tested whether cognitive stimulation, learning materials, and learning experiences predict socioemotional functioning at 12 months, and whether maternal postpartum depression or child sex moderate these links. Using ELPI 2010 data ($n = 1,721$), socioemotional development was assessed with the ASQ: SE and modeled as a second-order factor with four dimensions. A WLSMV model showed a good fit. Early learning indicators were constructed from HOME items. Structural equation models estimated direct effects, and multigroup analyses examined moderation following scalar invariance testing.

Results indicate that only cognitive stimulation significantly predicted socioemotional functioning at age 12 months ($\beta = -.24, p < .001$), such that higher levels of stimulation were associated with fewer socioemotional difficulties. Neither learning materials ($\beta = .00, p = .91$) nor learning experiences ($\beta = -.02, p = .58$) showed significant direct effects. Maternal postpartum depression was not directly associated with SED ($\beta = -.03, p = .36$), and no evidence emerged for the moderation of the stimulation–SED association ($\Delta\chi^2(1) = 0.00, p = 1.00$). Child sex did not predict global socioemotional functioning ($\beta = .11, p = .15$), although girls showed higher scores on the Affective factor ($\beta = .29, p = .049$). Across models, the results underscore that not all early learning inputs contribute equally to socioemotional adjustment in infancy; rather, cognitively stimulating



interactions—such as reading, verbal engagement, and age-appropriate play—appear to be the most relevant for supporting socioemotional well-being during the first year of life.

Overall, the findings highlight early cognitive stimulation as a key actionable pathway for strengthening infants' socioemotional development, with implications for parenting programs and early childhood policies aimed at enhancing caregiver–infant interactions. By distinguishing the effects of specific learning dimensions and testing variation across maternal and child characteristics, this study offers evidence to refine early intervention strategies in contexts where resources must be allocated efficiently.

Study 2: Father-child relationship quality and paternal involvement in children's socioemotional development: A parental dynamics analysis

Background. Research on the father's role in child-rearing and its association with children's socioemotional development has gained increasing attention, highlighting not only paternal involvement but also the quality of the father-child relationship. Moreover, understanding this relationship requires considering fatherhood as a dynamic system shaped by multiple factors, including individual characteristics, reciprocal interactions between caregivers, and cultural context.

Objectives. This study aims to examine how parental dynamics, including fathers' parental self-efficacy, beliefs about the paternal role, coparenting processes, and maternal gatekeeping, relate to paternal involvement and the quality of the father-child relationship, as well as how these factors are associated with children's socioemotional development (emotion regulation and social competence).

Methods. A total of 606 fathers of children aged 3 years ($M = 3.02$, $SD = 0.97$) participated in the study. Data were collected through father reports from different regions of Peru, with participants predominantly coming from lower-middle socioeconomic backgrounds within the Peruvian system.

Results. The findings from the structural equation modeling indicate that children's socioemotional development is explained by the quality of the father-child relationship, which is also explained by the parental dynamics variables ($\chi^2(29) = 759.63$, $p < .001$, $CFI = 0.96$, $RMSEA = 0.06$, $SRMR = 0.04$). None of the variables examined was associated with fathers' involvement. These results align with empirical evidence showing that relationship quality is a key factor in preschoolers' socioemotional development. This contribution is particularly relevant given the scarcity of research on these constructs in Latin America, especially within the Peruvian context.

Study 3: Beyond Behavior: Differential Longitudinal Effects of Parenting Beliefs on Child Development

Background. Early caregiving environments and parental belief systems may shape developmental trajectories across infancy and toddlerhood. However, the extent to which early maternal beliefs and psychological well-being prospectively predict behavioral adjustment and cognitive



development remains unclear, particularly in large community samples.

Methods. A longitudinal study was conducted with 1,161 mother–child dyads. Maternal beliefs about parenting practices (impact, hostility, overprotection, and self-efficacy; PACOTIS), maternal depressive symptoms (CESD), parenting stress (PSI), and migrant status were assessed when children were 12–18 months old. Child outcomes were measured approximately 18 months later, during home visits (approximately 36 months). Mothers completed the CBCL, and trained evaluators administered the Bayley Cognitive Scale.

Results. Early maternal beliefs involving hostility ($B = 1.40$, $p = .011$) and overprotection ($B = 1.13$, $p = .028$) predicted higher CBCL Total Problem scores at 36 months. Maternal parenting stress ($B = 0.065$, $p < .001$) and depressive symptoms ($B = 0.181$, $p < .001$) were strong additional predictors, increasing explained variance from 7% to 17%. Maternal migrant status did not predict later behavioral problems ($B = -0.64$, $p = .547$). For cognitive development, early maternal beliefs showed modest associations: impact predicted higher Bayley scores ($B = 1.04$, $p = .017$); overprotection predicted lower performance ($B = -2.19$, $p = .003$); and hostility emerged as a positive predictor in the fully adjusted model ($B = 1.75$, $p = .029$). Maternal stress ($p = .125$), depressive symptoms ($p = .636$), and migrant status ($B = -1.37$, $p = .369$) were not significant predictors of cognitive outcomes.

Conclusions. Maternal beliefs about parenting practices in infancy—particularly hostility and overprotection—are meaningful prospective predictors of behavioral difficulties in early childhood. Cognitive development appears less sensitive to maternal psychological distress and shows only small associations with early parenting beliefs. Supporting adaptive caregiving beliefs early in development may help promote healthier behavioral trajectories across early childhood.

Symposium 2.4 - Building blocks for learning: Self-generated activity in toddlers with Down syndrome

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Summary

Self-generated activity creates input for learning, forming the building blocks of cognitive and motor development. Down syndrome (DS) is a genetic condition resulting in cognitive and motor delays. This session presents 4 studies characterizing self-generated activity in toddlers with DS. Study 1 finds that toddlers with DS display fewer bimanual actions than typically developing toddlers, with a cascading effect on caregiver object labeling. Study 2 finds that children with DS display less object-specific differentiation of manual sampling than typically developing peers. Study 3 finds that the effect of walking experience on spontaneous stepping behavior differs for toddlers with and without DS. And Study 4 finds that pointing, the predominant deictic gesture for toddlers with DS, shows variable and nonlinear longitudinal trajectories. These studies highlight strengths and areas for growth in toddlers with DS, elucidating developmental mechanisms and opportunities for intervention.



Details

ABSTRACT 1, Object Manipulation and Caregiver Labeling: Dyadic Play in Infants with Down Syndrome:

Introduction: Infants with Down syndrome (DS) have significant delays in motor development that may have cascading effects on language and cognition. Recent studies in typically developing (TD) infants show that trajectories of *manipulation complexity (MC)* skills (i.e., bimanual manipulation, coordinating both hands, using varied finger combinations, and deconstructing objects) are positively associated with expressive and receptive language, and that caregivers are more likely to label objects when infants use more complex manual actions. Although object play offers a natural context for practicing fine motor skills and receiving rich language input, no studies have characterized manual actions during naturalistic play in infants with DS or examined the frequency of caregiver language input as a function of motor behavior in this population. In this study, we examined MC patterns in infants with DS relative to age-matched TD peers (aim 1), and caregiver object labeling in relation to infant object manipulation within the DS group (aim 2).

Methods: Participants were 11 infants with DS ($M \pm SD = 15.09 \text{ mos} \pm 3.72$) and 11 age-matched TD infants. Caregiver–infant dyads participated in 20-minute naturalistic in-home play sessions that were video- and audio-recorded. For aim 1, all instances of object contact were coded: bouts began when infants first touched an object and ended when contact ceased. Each bout was scored for manipulation complexity across four dimensions: (i) unimanual versus bimanual manipulation, (ii) synchronous versus asynchronous hand use, (iii) dependent versus independent finger use, and (iv) whether both hands manipulated a single object or multiple parts of a multi-piece object. Frequencies and proportions of each manual action were calculated per session. For aim 2, three at-home visits per infant with DS were analyzed. Caregiver utterances were transcribed to identify object labels (e.g., *ball*, *block*). Labeling frequency was calculated as the number of labeling utterances during infants' object manipulation bouts.

Results: Infants with DS engaged in more frequent bouts of object contact (44.57 ± 15.38) than TD peers (33.14 ± 14.35) and demonstrated lower motoric complexity. They produced a significantly higher proportion of unimanual actions ($MDS = 0.45 \pm 0.15$; $MTD = 0.33 \pm 0.17$), $p < .05$, and were significantly less likely than TD peers to use asynchronous bimanual actions, independent finger movements, or object deconstruction behaviors, all $p < .05$.

Preliminary analyses of 19 of 33 at-home visits with DS dyads revealed comparable frequencies of unimanual (21.14 ± 10.09) and bimanual actions (23.43 ± 11.85). On average, caregivers were more likely to provide object labels during bouts of bimanual actions (4.01 labels $\pm$ 3.31) compared to bouts of unimanual actions (2.20 labels $\pm$ 1.50), $p < .05$. Additionally, caregivers were more likely to provide object labels during longer ($32.46 \text{ seconds} \pm 22.62$) than shorter ($21.75 \text{ seconds} \pm 27.03$) bouts of object play, $p < .05$.

Conclusions: Preliminary results suggest that infants with DS were less likely to make use of bimanual actions compared to TD age-matched peers. But because caregiver labeling occurs more frequently during bimanual compared to unimanual actions, caregivers of infants with DS may have fewer opportunities to provide object labels during play with their infants.



ABSTRACT 2, Young children with Down syndrome show less object-specific differentiation in manual sampling:

Infants adapt to their environments by learning how to *sample* manual information efficiently (Gibson & Pick, 2003). As they gain experience, manual behaviour becomes increasingly specific: broad, general movements gradually give way to differentiated actions directed toward particular targets (Thelen & Smith, 1994; Rachwani et al., 2020). Because this fine-tuning process is shaped by experience (Spencer et al., 2011), variations in early motor abilities may alter its developmental course. Young children with Down syndrome (DS) experience pervasive motor difficulties, the developmental impact of which is yet to be fully understood (D'Souza & D'Souza, 2020). We hypothesised that as young children with DS may have reduced opportunities for manual sampling, this could lead to atypical manual differentiation. Yet empirical evidence remains limited.

The main goal of this study was to compare the duration of manual sampling episodes across multiple objects in typically developing young children and those with DS. We expected that children with DS would show less differentiation between objects.

We compared typically developing (TD) toddlers ($n = 15$, age: $M = 21.2$ months, $SD = 2.9$) with young children with DS ($n = 15$, age: $M = 47$ months, $SD = 7.9$) during play with caregivers. The two samples were group-matched based on ability level using the Mullen Scales of Early Learning (Mullen, 1995).

Each caregiver-child dyad was seated across a table and played with six objects (two sets of three objects, with set order counterbalanced) for 6 minutes in total ($Mdn = 6.43$ minutes, $IQR = 0.16$). A linear mixed-effects model examined how the duration of a sampling episode (log-transformed for normality) varied across objects and groups.

There was no significant overall difference in the duration of sampling episodes between groups ($F(1) = 3.91$, $p = .054$), although trending with TD showing longer sampling durations. However, a significant interaction between groups and object was found ($F(8) = 17.52$, $p < .001$, $\eta_p^2 = .04$). Follow-up contrasts revealed that TD toddlers showed differentiated manual sampling between objects in both sets (set 1: object 1 vs. 2 (estimate = $-.77$, $p_{\text{bonf}} < .001$, Cohen's $d = -.48$); object 1 vs. 3 (estimate = $-.81$, $p_{\text{bonf}} < .001$, Cohen's $d = -.51$); set 2: object 1 vs. 3 (estimate = $-.79$, $p_{\text{bonf}} < .001$, Cohen's $d = -.34$); object 2 vs. 3 (estimate = $-.55$, $p_{\text{bonf}} < .001$, Cohen's $d = -.50$). In contrast, children with DS showed differentiation only in one set (set 1: object 1 vs. 2 (estimate = $-.54$, $p_{\text{bonf}} = .002$, Cohen's $d = -.34$); object 1 vs. 3 (estimate = $-.91$, $p_{\text{bonf}} < .001$, Cohen's $d = -.57$); set 2: no significant differences between objects). These findings indicate that children with DS exhibit less object-specific differentiation in manual sampling than the ability-matched TD group. Understanding how children with DS experience early sampling behaviour offers valuable insight into atypical fine-tuning processes. Such knowledge can support the development of early play-based assessments and interventions that enhance infants' adaptive motor strategies, which are foundations for later motor and cognitive development.

ABSTRACT 3, Characterizing Spontaneous Locomotion in Infants with Down Syndrome:



Introduction: Infants with Down syndrome (DS) exhibit delays in walking onset and less mature gait than their typically developing (TD) peers. However, little is known about how infants with DS walk in naturalistic environments. Prior research shows that independently walking TD infants take high proportions of short and curved bouts and that these characteristics remain stable across walking experience. The primary goals of this study were to characterize spontaneous stepping in cruising and walking infants with and without DS and to examine the effects of walking experience on spontaneous stepping.

Participants: 30 TD infants (9-18 months of age) and 16 infants with DS (19-35 months); all could cruise (9 TD, 3 DS) or walk independently (21 TD, 13 DS).

Methods: Infants played with their caregiver in a lab playroom for 20 minutes. Walk onset was collected via caregiver report, during the session for walkers or via follow-up phone call for cruisers. Walk experience was calculated as the session date minus the walk onset date (negative for cruisers, positive for walkers). From video, coders identified each bout of stepping, and scored the number of steps, whether the bout was independent or supported, and whether the bout was curved or straight. Analysis assessed effects of group (TD vs. DS), walking experience, and the group*walking experience interaction on bout characteristics. Multiple linear regression was used to analyze overall number of steps, linear mixed models were used for steps per bout, and generalized linear mixed models were used to assess the probability of bouts being short (1 step), long (>10 steps), independent, and curved. Significant interactions were followed up by estimating simple effects of walking experience for each group.

Results: There were no overall differences in spontaneous stepping between infants with and without DS: the groups took similar numbers of steps overall and per bout, and bouts were equally likely to be independent and curved. However, there were several significant group*walking experience interactions (Figure 1). Walking experience was associated with an increased step rate for TD infants ($B=7.20$, $p<0.001$) but not for infants with DS ($B=1.62$, $p=0.14$). On the bout level, for TD infants only, increased walking experience was associated with more steps per bout ($B=0.76$, $p<0.001$), fewer short bouts ($OR=0.76$, $p<0.001$), and more long bouts ($OR=1.47$, $p<0.001$). For infants with DS, increased walking experience did not reflect changes in steps per bout ($B=0.01$, $p=0.92$), or number of short ($OR=1.02$, $p=0.42$) or long ($OR=0.99$, $p=0.99$) bouts. For all infants, increased walking experience was associated with more curved bouts ($OR=1.31$, $p<0.001$) and more independent bouts ($OR=2.00$, $p<0.001$). There was a significant group*experience interaction for independent bouts: For TD infants, walking experience had a greater effect on independent bouts ($OR=2.60$, $p<0.001$) than for infants with DS ($OR=1.17$, $p<0.001$).

Conclusions: Findings suggest that infants with DS display different developmental trajectories in spontaneous walking compared to their TD peers. Specifically, properties of spontaneous walking change less with walking experience in infants with DS.

ABSTRACT 4, Measuring Deictic Gesture Use in Toddlers with Down Syndrome Over Time:

Introduction: Research on children with Down syndrome suggests that gestures are commonly used to supplement or support communicative and social interactions (Caselli et al., 1998; Zampini & D'Odorico, 2011). Thus, gesture use is often described as a robust skill. In early



development, deictic gestures—point, show, give—allow for communication about needs, wants, and interests even when little or no spoken language is present. Using deictic gestures to communicate capitalizes on the strengths in receptive language and weaknesses in expressive language associated with Down syndrome. However, most research on gesture use in Down syndrome has been conducted in cross-sectional samples across a large age range, and little is known about how deictic gesture use changes over time. Gesture research in Down syndrome tends to be analyzed as either a total gesture variable or by category (i.e., deictic), rather than by type (i.e., point; Mattie et al., in press). However, the type of gesture is key because it provides insight into the intention of the social/communication act and has implications for identifying treatment targets and supports (Capone & McGregor, 2004). The present study explores point, show, and give gestures in a longitudinal sample of toddlers with Down syndrome.

Participants: 14 toddlers with Down syndrome, 18-30 months ($M = 23.49$, $SD = 4.46$) at Time 1.

Method: All participants had 3 or 4 timepoints. At Time 1, mothers completed the Vineland Adaptive Behavior Scales 3rd Edition as a proxy for developmental level. Toddlers had an average adaptive behavior composite of 71.57 ($SD = 6.61$) and an age equivalence of 12.74 months ($SD = 3.40$). At each time point, a mother-child free play was administered with a standard set of toys for 15 minutes. This was recorded and coded for gesture use point, show, and give. Gestures were coded second by second in Noldus the Observer XT as point estimates. Time 4 data is currently being coded.

Results: Pointing was the most common gesture used at all timepoints ($M_1 = 6.21$, $SD_1 = 7.40$; $M_2 = 11.86$, $SD_2 = 7.64$; $M_3 = 8.29$, $SD_3 = 8.73$). Showing and giving occurred infrequently during the 15 minutes across the 3 timepoints (Show: $M_1 = 3.57$, $M_2 = 3.07$, $M_3 = 1.78$; Give $M_1 = 1.79$, $M_2 = 3.43$, $M_3 = 3.57$). Highlighting how a single gesture type could drive a gesture category.¹⁰ Visual inspection of the data indicated that use of each gesture type varied greatly from toddler to toddler and age to age (Figure 2). Given the developmental level of the sample, we expected to see evidence of linear growth, but it appears that deictic gesture use is nonlinear, at least in this sample and sampling context. Nonlinear regression will be presented to explore the association between deictic gesture type and age, as well as other potential predictors of change, such as language ability a use of sign language. The influence of sampling context and length of time on the measurement of gesture use will be discussed.

Symposium 2.5 - Rethinking verb learning: integrating multiple methods for new insights

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Summary

Understanding how infants learn verbs requires capturing how actions unfold in real time and how linguistic, perceptual, and neural cues shape verb mapping. This symposium brings together complementary approaches to study verb learning. **Presentation 1** uses EEG to show that infants



differentiate matching and mismatching verb–action pairs, highlighting early processing of verb–event relations. **Presentation 2** uses a Human Simulation Paradigm to show that temporal alignment between verbs and infant actions provides powerful cues to help learners infer verb meaning. **Presentation 3** combines head-mounted eye tracking with a generalization task to quantify natural verb–action pairings and test whether children can learn verbs from naturalistic exemplars. Together, findings integrate neural, behavioral, and experimental methods to reveal how infants extract meaning from dynamic events. **A discussant** will synthesize findings and consider how multimodal evidence advances verb learning theories.

Details

Abstract 1, Title: Electrophysiological evidence of infants’ understanding of verbs

Children’s spoken and receptive vocabularies feature nouns heavily during early development despite linguistic input from caregivers frequently incorporating other word types such as verbs (Au et al., 1994; Goldfield, 2000; Sandhofer et al., 2000; West et al., 2022, 2023). The prevalence of nouns in early vocabulary likely explains why experimental research has often focused on when and how infants begin mapping objects to nouns – with studies showing that infants understand several nouns by 9 months (Bergelson & Aslin, 2017; Bergelson & Swingley, 2012, 2015; Parise & Csibra, 2012; Tincoff & Jusczyk, 1999, 2012). Much less is known about when infants begin grasping the meaning of verbs. Learning verbs – words that describe actions, events, and processes – is a complex process. Theorists suggest that infants must employ sophisticated word and action segmentation, event processing, and verb-to-action mapping skills (Gentner, 1982; Golinkoff et al., 2002). Yet, prior research suggests these skills are available to infants within the first year of life, by at least 10 months.

In the current study, we asked whether 10-month-old infants show evidence of verb understanding in a novel EEG paradigm using videos of everyday actions. Using a data-driven approach to select verb items based on CDI data, we showed infants short videos depicting familiar actions while hearing verbs that matched (e.g., a video of someone drinking from a cup while hearing the verb “*drink!*”) or mismatched the action (e.g., a video of someone walking across a room while hearing the verb “*kiss!*”). To validate our paradigm, we tested adult participants on the same paradigm to investigate whether action-verb pairs reliably evoke an N400 response associated with lexical-semantic violation (Junge et al., 2021; Kutas & Federmeier, 2011). This also allowed us to document how the topography and time course of neural responses to actions-verbs pairs may differ across different stages of development. Adults showed a robust N400 response, with more negative amplitudes to mismatched versus matched action-verb pairs, across frontal and centroparietal regions, consistent with prior work using simultaneous action and auditory speech (Amoruso et al., 2013). Infants also showed greater negativity to mismatches in frontal regions, along with polarity reversed effects in central and parietal sites. These findings suggest that infants were sensitive to mismatches between actions and labels, suggesting emerging verb knowledge by at least 10 months. We additionally tested whether infants’ vocabulary size was related to the strength of their frontal ERP effect but found no evidence of such a relation. We consider whether these infant ERP differences reflect early semantic-violation processing or instead a precursor to forming robust action-verb representations. By presenting infants with naturalistic videos of actions paired with spoken verbs, our findings offer new evidence on how verb understanding



begins developing in the first year of life. This work aligns with this symposium's focus on verbs and naturalistic input by introducing a novel method for capturing infants' emerging sensitivity to the meanings of verbs they frequently encounter in their daily lives.

Abstract 2, Title: Infant motor actions disambiguate verb meaning: Evidence from a human simulation paradigm

Infants' motor actions often temporally correspond to their verb inputs; Approximately half of caregivers' verb inputs align precisely to infants' ongoing actions (e.g., caregiver says "go" while infant locomotes, or "open" as infant removes a lid). Embodied learning theories propose that infants' real-time motor actions function as self-generated cues that help them decipher verb meanings. However, whether temporal alignment between verbs and action indeed helps disambiguate a verb's meaning requires experimental evidence. We used adult raters to test whether the alignment of input with infant action supports verb learning more than other moments (i.e., times when verbs are not aligned with infant actions).

Adult raters ($N = 600$) watched twenty-four 6-second video clips of caregiver-infant interactions drawn from home observations of infants and their caregivers, in which the caregiver said a whole-body verb—like "jump" or "climb"—or a manual verb—like "press" or "clap". In half the video clips, the verb was aligned with the infants' simultaneous action (e.g., the caregiver said "jump" as infant jumped); the other half were not. In half the clips, the verb was transitive (referred to an object, e.g., "press button"); the other half were intransitive (e.g., "clap", "jump"). In every video clip, the verb was omitted. For some participants, the verb was covered by a tone (e.g., "close the lid" was presented as "[TONE] the lid"). For other participants, the video was muted entirely, so participants could not use the sentence frame to decipher the verb. A third group read transcript of the caregivers' utterances, with the key verb removed, without viewing the video. Participants were asked to identify the missing verb.

Hierarchical linear modeling was used, with trials nested within participants, and participants nested within groups (captioned video, muted video, or transcript only). The alignment between verb and infant action enhanced participants' ability to identify the missing verb. For both whole-body and manual verbs, participants identified the correct verb more often when it aligned with the infants' actions ($M_s = 84.17\%$ and 83.33% for whole-body and manual verbs respectively; $SD_s = 15.17, 16.17$) compared to when it did not align with the infant's action ($M_s = 61.0\%$ and 61.33% for whole-body and manual verbs respectively; $SD_s = 17.5, 20.83$). Overall, participants performed worse at guessing the verb when the video was muted ($M = 58.39$; $SD = 16.38$) compared to when the verb was omitted with a tone ($M = 72.55\%$; $SD = 11.31$), suggesting that participants benefited from knowing the syntactic context of the verb's use. [Note: Participants' were greater than chance in all conditions, further suggesting that the broader environmental cues, such as the presence of a ball in front of the child, likewise function to support learning.]

Recent work on verb learning proposes a possible behavioral cascade wherein: (1) caregivers tailor their verbs to infant actions, and in turn, (2) the infants' action serves as a salient clue to the verb's meaning. Our data demonstrates that infants' actions can serve as powerful indicators of a verb's meaning.



Abstract 3, Title: The Role of Attention in Verb Learning: Insights from Head-Mounted Eye Tracking During Everyday Activity

Research on early language acquisition has predominantly focused on how infants learn nouns, with far less attention to verbs, despite verbs' critical role in conveying relational meanings. Verbs pose unique learning challenges because they refer to dynamic, often fleeting events rather than stable objects. Two sources of ambiguity complicate verb learning. Word–referent ambiguity arises because actions unfold rapidly, and caregivers often mention verbs before or after the relevant action occurs. Word–meaning ambiguity arises because the same verb can be conducted with different objects, actors, and motion patterns, making it difficult for infants to discern which properties are essential for meaning. Most experimental studies assume idealized conditions in which infants attend to a single, clearly presented novel action, whereas most naturalistic studies examine verb frequency without considering referent availability. Here, we address each source of ambiguity using methods that bridge together naturalistic observation and experimental testing.

Study 1 quantified the statistics of everyday verb input to assess word–referent ambiguity. We examined parent verb use in two contexts: free play and meal preparation. In the play task, 31 parent–infant dyads (12–25 months; $M = 19.25$) played for 10 minutes with 24 toys (Figure 1A). In the meal-preparation task, 31 parents made peanut-butter and jelly sandwiches while infants (13–31 months; $M = 20.37$) sat across from them (Figure 1B). Both contexts took place in a home-like lab, and both partners wore head-mounted eye trackers. Parent speech was transcribed, and utterances containing concrete action verbs were identified. Coders noted whether the referenced action occurred within a three-second window, and whether infants looked at the action.

Across contexts, the statistics supporting verb learning were similarly sparse. Parents used verbs frequently (play: 2.79/min; meal prep: 3.05/min; Figure 1C). However, only about two-thirds of verbs overlapped in time with the action (play: 62%; meal prep: 66%; Figure 1D), and infants looked at the action during only two-thirds of those moments (play: 63%; meal prep: 69%; Figure 1E). Thus, fewer than half of verb tokens provided high-quality learning opportunities (play: 39%; meal prep: 46%; Figure 1F). Verb knowledge data from a subset of the meal-preparation sample revealed that caregivers were more likely to time unfamiliar verbs to ongoing actions ($b = 0.23, p = .02$), and parents who used more verbs had children who knew more verbs ($b = 0.21, p = .04$), suggesting structured—not random—input.

Study 2 addressed word–meaning ambiguity using an experiment grounded in naturalistic data from Study 1. We selected high-quality verb–action instances from infants' first-person videos in the meal-preparation task and used them as stimuli in an online learning study. Infants viewed multiple exemplars of four actions (scoop, spread, cut, wipe), each paired with a novel verb (Figure 2), and were later tested on generalization to new actors and motions using a forced-choice looking measure (Figure 2). Preliminary data from 2- and 3-year-olds will be presented.

Together, these studies bridge naturalistic and experimental approaches to reveal how the structure of everyday experience supports early verb learning.



Symposium 3.1 - Visual rhythms in infant environments: implications for attention, learning, and communication

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Summary

Infant environments are rich in multimodal rhythms. This rhythmicity is proposed to make the world more predictable for infants and to promote interpersonal synchrony. Our symposium presents converging evidence on how rhythms in the visual domain guide infant attention and support early communicative development. The featured studies use diverse methods including EEG and pupillometry with infants in their first year of life. Talks 1 and 2 focus on rhythmicity in biological signals (face and body movements). Talks 1 and 3 focus on the role of rhythm in word-learning and vocabulary development. All three consider the factors that shape early rhythm processing, and the role of social cues like language, movement, and touch. Integrating the presented studies with existing research on rhythmicity across modalities, our discussant will situate the results within a theoretical framework that highlights the role of multimodal rhythmicity in caregiver–infant interactions.

Details

Abstract 1: Infants' tracking of and attention to visual rhythmic speech in the first year of life is related to language development

There is a growing body of findings about how tracking of speech in infancy relates to language development. Much of this work emphasises the auditory domain, but infant-directed speech is a multimodal stimulus. The rhythms of speech are visible in the movements of the face, and it has been suggested that attention to a speaker's face can support phase-resetting during speech tracking. Attention to a speaker's mouth increases around 8 months of age, around the same time that infants begin to understand common words.

We used EEG to study cortical tracking of rhythmic speech in infants longitudinally from 8 weeks to 11 months of age. Stimuli were repeated syllables and naturalistic infant-directed nursery rhymes, accompanied by a video of the speaker's face. Cortical tracking of these audiovisual (AV) stimuli was associated with measures of language development, specifically vocabulary size at 24 months of age. At the ages of 5 and 8 months, infants viewed a muted, visual-only (VO) version of the repeated syllables. We anticipated that infants would cortically track the VO speech stimuli, and that visual tracking would also be related to language outcomes.

Using linear mixed effects models with factors of condition (visual stimulation versus rest) and frequency bin (2 to 7Hz), we found a significant increase in cortical power during 2Hz stimulation (the rate at which the syllables were produced; $\beta = 0.34$, $p = 0.002$). We also found significant phase alignment during 2Hz stimulation ($\beta = 0.1$, $p = 0.017$). The AV stimuli had shown evidence of a group level "preferred phase", meaning that the lag between stimulus and response was similar



across infants. For the VO stimuli, there was no preferred phase at 5 months (Rayleigh statistic: $Z = 1.565$, $p = 0.21$). However, at 8 months, there was evidence of a group-level preferred phase ($Z = 3.206$, $p = 0.039$). Furthermore, phase alignment at 8 months was related to productive and receptive vocabulary size at 24 months (circular-linear correlations, $p < 0.025$), indicating that tracking the visual rhythms of speech may support language development.

Eye-tracking was used during AV and VO paradigms to explore infants' attention to the speaker's mouth, and find if this related to later language development. There was substantial inter-individual variability in looking preferences. At 11 months of age, looking to the mouth of a speaker was inversely related to receptive vocabulary size among monolingual infants at 24 months ($p < 0.025$). Thus, lower reliance on visual speech information by this age is associated with better language outcomes. However, among multilingual infants, there was an increase in attention to the speaker's mouth in the IDS stimuli with age, and attention to the mouth at 11 months of age was associated with a larger vocabulary at 24 months ($p < 0.05$). For infants who hear multiple languages, there may be an extended role of visual speech information in supporting language development. Across measures, results point to the importance of visual information in infant speech processing and its later effects on language development.

Abstract 2: Neural tracking of rhythmic biological motion in infants

Rhythmicity in infant environments is thought to support learning and interpersonal coordination. In the visual domain, infant brains robustly track rhythmic movements of the face and the mouth during speech production, and this tracking relates to language development (Ní Choisdealbha et al., 2024). Another type of a significant rhythmic social signal in infants' visual environments is the bodily movement of others during locomotion, the processing of which likely plays a role in the perception of others' actions and interpersonal coordination. In a paradigm using Point Light Walkers (PLWs) moving at a rhythmic pace, previous research demonstrated that adult brains track the rhythmicity of others' bodily movement (Cracco et al., 2022). However, to date, no study has investigated whether this is also the case for infant brains, and what factors relate to this ability. In our preregistered study with 3-month-olds ($n = 34$) and 6-month-olds ($n = 38$), using a paradigm adapted from the study investigating this phenomenon in adults (Cracco et al., 2022), we recorded EEG while infants were presented with PLWs moving at a rhythmic pace of 2.4 Hz (one step every ~ 417 ms) on a computer screen. Half of the displays were upright, and half inverted (within-participants). Additionally, we collected questionnaire measures relating to caregiver touch-related behaviours towards their infants, as previous research indicated a link between caregiver touch and infant processing of social information. We hypothesised that 1) we will observe stronger neural tracking of upright vs. inverted biological motion in both age groups, 2) this effect will be stronger in 6-month-olds, as compared with 3-month-olds, and 3) caregiver touch will positively relate to infant processing of upright biological motion.

To quantify neural tracking of the rhythmic movement of the PLWs, we calculated baseline-corrected amplitudes at the frequency of movement (2.4 Hz) and its two harmonics (4.8 Hz and 7.2 Hz). We found that 3-month-olds as well as 6-month-olds neurally tracked rhythmic biological motion, both upright and inverted (Figure 1). Contrary to our hypothesis, neural tracking was stronger for inverted as compared with upright biological motion ($d = 0.18$, $p = .03$), and there were no differences between age groups in this regard ($p > .90$). However, consistent with our hypothesis, we found that across ages, caregiver attitudes towards touch positively predicted



neural tracking of upright ($d = 0.29$, $p = 0.003$), but not inverted ($p = 0.88$) biological motion (Figure 2).

Our results demonstrate that, already within the first months of life, infant brains are capable of tracking the rhythmicity of others' movements. Additionally, caregiver touch may play a role in infants' processing of rhythmic upright biological motion specifically—a particularly socially relevant cue. We will discuss our findings in the context of the role of rhythmicity in infants' social environments.

Abstract 3: Effects of temporal predictability on attention and word-object association learning: A pupillometry study

Introduction: The temporal predictability of events facilitates the allocation of attention over time, resulting in cascading improvements in both visual and auditory perception. In adults, stimuli presented in phase with a predictable temporal structure are processed more efficiently than those occurring out of phase (Elbaz & Yeshurun, 2020; Jones & Boltz, 1989). Similar effects have been observed in early infancy, with rhythmic structure enhancing the detection of auditory violations already at birth (Suppanen, Huotilainen, & Ylinen, 2019). However, no studies to date have investigated the role of temporal predictability in facilitating learning outcomes during early infancy.

Objective & hypothesis: We addressed this question by examining the role of temporal predictability in infants' learning of novel words: We hypothesized that presenting information in a temporally predictable manner would facilitate the learning of novel word-object associations at 12 months.

Method: To this end, we exposed two groups of 10- to 12-month-old infants to novel word-object associations presented in either a temporally predictable or unpredictable manner and examined how temporal predictability influenced learning. The task consisted of two phases: learning and test. During the learning phase, infants viewed familiar visual objects, among which two novel word-novel object pairs were embedded. In the predictable group ($N = 16$), the familiar objects and novel word-object associations were presented following a regular temporal pattern (1500 ms on, 500 ms off). In the unpredictable group ($N = 17$), the same stimuli were presented in an irregular and temporally unpredictable manner (on range: 500-1500 ms; off range: 500-800 ms). During the test phase, infants' learning of the word-object associations was assessed using a looking-while-listening paradigm. During the task, an eye tracker was used to record eye movements, looking times, and pupil dilation, with the latter indexing attentional allocation over time (Hepach & Westermann, 2016). To examine the dynamics of attention allocation during the familiarization phase, we conducted a stepwise linear mixed-model to test whether pupil dilation varied as a function of time, stimuli, and groups. To assess learning outcomes, the same model was used to test whether pupil dilation and looking times at test differed between target and distractor stimuli and across groups.



Results: Data collection is ongoing. Preliminary results showed that, during the learning phase, pupil dilation in response to the novel word-object association trials decreased over time only when the timing of stimuli was predictable, $F(2,290644) = 7.11$, $p < .001$, suggesting that temporal predictability reduces the cognitive demands of learning across trials. Although looking times during the test phase did not differ between stimuli and groups (all $ps > .63$), pupil dilation of infants in the predictable group was greater in response to the target immediately after the label was pronounced, $F(1, 2663.7) = 6.28$, $p = .01$. These preliminary findings suggest that predictable temporal rhythms may support early word learning by guiding infants' attention to relevant linguistic input, enhancing the encoding of new word-object associations. Furthermore, these data highlight pupillometry as a valuable tool for studying individual differences in visual attention deployment.

Symposium 3.2 - The emergence of object category knowledge: indicators and potential processes of concept formation

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Summary

Infants begin learning object categories early in life, from recognising category-defining features to acquiring labels. This symposium will provide new insight into the origins of conceptual development. Talk 1 uses machine-learning approaches to EEG to show that neural object representations are modulated by infants' category knowledge. Talk 2 uses an eye-tracking category Match-to-Sample task to capture developing category knowledge in 10- to 20-month-olds and examines how this links to word knowledge. Talk 3 reveals that consistent labelling helps infants form categories but not (initially) learn the associated words. Talk 4 shows how sleep consolidation helps infants shift from item-level representations to forming category-level representations, supporting generalisation. Together, these talks will reveal novel techniques for measuring infants' emerging concepts and illuminate the processes that shape category formation.

Details

Abstract 1: Neural markers of prior category knowledge: Decoding object representations using multivariate approaches to infant EEG

Humans parse their visual world into categories based on their existing object category knowledge, classifying things they see into cups, tables, apples, etc. When adults encounter an object, they have already inferred its basic-level category membership by the time they are consciously aware of seeing it (Grill-Spector & Kanwisher, 2005). During visual processing, this categorical information takes precedence over exemplar specific information. Categorical prioritisation is also reflected in neural object representations; induced gamma oscillations exhibit greater synchrony when visually processing an object from a familiar category compared to an unfamiliar object, representing



conceptual access (Gruber & Müller, 2005). Whether categorical knowledge also modulates infants' neural object representations remains an open question. Behaviourally, infants also focus on categorical over individual features when observing objects (Althaus et al., 2020; Kibbe & Leslie, 2019; Xu et al., 1999). Some evidence suggests that infants' neural processing of objects is also moderated by familiarity; gamma-band oscillations in response to objects are enhanced when infants know the category label versus those for which they don't have a label (Gliga et al., 2010) and modulations of theta-band oscillations during object encoding predicts whether infants will recognise an object later (Bergus et al., 2015).

Here, we extend prior work by capturing 12-month-old infants' neural representations of familiar (acquired from their day-to-day experiences) and unfamiliar categories. We used an EEG category change detection paradigm (Pomiechowska & Gliga, 2021) to show infants objects from six familiar (e.g., ball, book) and six unfamiliar categories (e.g., stapler, padlock), based on CDI language norms. During this task, an object from a familiar or unfamiliar category appeared on a screen before being briefly occluded and then revealing a within- or across-category object change. To capture category knowledge, we used two approaches. We first used univariate ERP analysis of the Negative Central (Nc), previously found to be greater for across (versus within) category changes for familiar, but not unfamiliar, categories (Pomiechowska & Gliga, 2021). We also applied Multivariate Pattern Analysis (MVPA) during initial object presentation to test whether category familiarity can be decoded from infants' neural representations – a method has shown recent promise in disentangling infants' neural organisation of visual categories (Xie et al., 2022). During initial object presentation, we trained a machine learning algorithm (Bae & Luck, 2018) to detect patterns of neural activity associated with familiar and unfamiliar categories – classifiers were trained separately for each infant and each moment in time. Our findings show that infants' object representations are modulated by their category knowledge, with distinct neural representations for familiar and unfamiliar categories identified in gamma- and theta-band oscillations. In contrast, we found no differences in the Nc ERP (between within- and across-changes) for either familiar or unfamiliar categories, highlighting how multivariate techniques can detect subtle differences in neural activity that are challenging to capture with traditional approaches. These results offer a window into how infants' conceptual knowledge shapes their neural processing, aligning with this symposium's aim of uncovering both the origins and indicators of early concept formation.

Abstract 2: Measuring Infants' Existing Category Knowledge and its Link to Vocabulary Using an Implicit Match-to-Sample Task

Infants as young as 4 months can learn a variety of categories from perceptual features alone (e.g., cat, car; Quinn et al., 1993; Quinn & Eimas, 1996). Prior studies tend to familiarise infants with a novel category by showing exemplars one after the other in close temporal succession. This is not reflective of real-world experiences and encounters that are often characterised by long intervals between category exemplars, interleaving stimuli, and high variability in category exemplars. When 12-month-olds are presented with interleaved exemplars, more like the 'real-world', they are unable to learn new category labels (Pomiechowska & Gliga, 2019). Therefore, typical lab-based familiarisation studies may only show us how children learn new perceptual categories in ideal situations and tell us little about the emergence of early category knowledge in messy real-world situations. There is also uncertainty surrounding the role of language in category learning. While we know that conceptual and word knowledge are tightly intertwined in adults (Connell, 2019), little is



known about how or when this link emerges. Research suggests this link may emerge early whereby labels help infants learn new categories (Althaus & Westermann, 2016; LaTourrette et al., 2023). Others, however, suggest categories can be learnt without labels (Ferguson & Waxman, 2017 for a review). This study examines these issues, building an understanding of the object categories learnt early in development and how this might link to knowledge of category labels.

We have developed a novel, eye-tracking adaptation of a Match-to-Sample paradigm that aims to quantify existing knowledge of 12 object categories children may have acquired prior to visiting the lab. The task measures children's in-the-moment category matching behaviours by examining whether, when presented with an exemplar object, infants can identify a 'matching' (within-category) object against a 'distractor' (out-of-category) object (Kaldy et al., 2016). We are examining the time-course of looking behaviour during this task across a sample of 10- to 20-month-olds. Data collection and analysis is ongoing. Preliminary findings from an initial sample of 14 infants demonstrate that knowledge of these object categories is emerging across this period. Older children ($n = 8$, 18-20 months), show greater looking to the match object than the distractor ($\beta = 3.62$, $SE = 0.51$, $p < .001$), than younger children ($n = 6$, 10-12 months). We are also collecting concurrent measures of word knowledge, using parental report from the Oxford CDI (Hamilton et al., 2000), to explore whether category knowledge exists prior to or without word knowledge. Preliminary findings suggest object category knowledge is linked to vocabulary knowledge. When infants knew the label for a category, they demonstrated greater looking to the match object than to the distractor ($\beta = 1.99$, $SE = 0.62$, $p = .001$), than when they did not know the category label. Altogether, these findings highlight that this new task can capture an improvement in object category knowledge emerging across development and demonstrate that this knowledge is linked to word learning and knowledge of category labels. Thus, we find no evidence for category knowledge preceding word knowledge.

Abstract 3: When cues shape concepts: Labels guide category formation before representations are learned

A central theme in understanding the origins of category knowledge is identifying how infants extract coherent categories from variable input and which cues in their environment facilitate this process. Labels have been proposed to function not merely as names but as organising signals that highlight commonalities among objects. From this perspective, category formation is supported when infants encounter cues that help structure their perceptual input even before these cues are fully represented as part of their explicit knowledge. To examine how labels and visual experience jointly contribute to early category formation, we tested 80 twelve-month-old infants in a paradigm combining a visual category-learning task and a word-object associative-learning task, with the order counterbalanced across infants. Each task was manipulated to be either supportive or unsupportive of learning: category learning was encouraged through blocked presentation of category exemplars (or disrupted through interleaving), and word learning was made possible through consistent (or disrupted through inconsistent) labelling. This approach allowed us to assess not only whether infants succeeded in each task, but also whether learning in one domain predicted or scaffolded learning in the other. Our preliminary findings reveal an asymmetry: Infants were more likely to form object categories after hearing consistent labels, even though they did not reliably learn the individual word-object associations. In contrast, prior category formation did not



enhance subsequent associative word learning. Methodologically, this suggests that category knowledge can be detected even when infants fail to show evidence of lexical learning, highlighting the value of combining category-based and associative tasks to dissociate different sources of influence.

Theoretically, these findings contribute to the symposium's focus on the origins and organisation of early categories: they suggest that labels can act as structuring cues that guide infants toward grouping objects by deeper shared features, supporting category formation without requiring explicit lexical knowledge. This implies that infants' early conceptual systems may be shaped by informative cues in the environment, such as consistent labelling, even before those cues are represented as stable, learned facts.

Abstract 4: Evidence of categorical knowledge acquisition from distributional information in 5-month-old infants

Understanding how infants rapidly learn from a vast, predominantly probabilistic input is a central question in the developmental sciences. Encoding the probability of each encountered association is costly and yields precise knowledge that is not generalisable to new instances, hindering the learning of intrinsic patterns. On the contrary, neglecting item details and low-frequency associations would lead to generalisation and, potentially, to the formation of condensed representations (Benjamin et al., 2023). While we know infants form natural categories very early on (Mareschal & Quinn, 2001), little is known about how they learn from them. Do infants form associations at the item level or do they operate at the category level, thereby promoting generalisation and reducing complexity? In this study, we aim to address this question.

We used high-density EEG to test how 5-month-old infants encode and consolidate the associations between two images, with the first image belonging to a natural category (birds or mammals) and predicting the second image (a shape). The experiment had four phases (Figure 1): (1) Pre-learning: presentation of all the possible animals, (2) Learning: first presentation of the trials with associations, (3) Consolidation: nap, (4) Test: new presentation of trials with the associations. Infants napped during the consolidation to promote generalisation (Friedrich et al., 2015). In each trial, an animal image was followed by a shape. If A denotes one category and B the other, and A_i and B_i denote the items in each category, then $P(X|A_i)$ and $P(Y|B_i)$ vary across the different images A_i , B_i . Critically, the $P(X|A)$ ($P(Y|B)$) at the category level was set to 0.75, while some examples of each category were equally likely to be followed by any of the shapes, $P(X|A_i) = P(Y|A_i) = 0.5$ ($P(Y|B_i) = P(X|B_i) = 0.5$).

EEG was acquired with the NetAmps 300 EGI amplifier using a 124-channel HydroCel net. Data were preprocessed using the APICE pipeline (Fló et al., 2022), applying a 0.2 Hz high-pass filter, a 15 Hz low-pass filter, and a reference to the average. Evoked responses were computed by epoching the data from the onset of the animals' images $[-0.6, 1.0]$ s and the shapes' images $[-1.0, 2.2]$ s, with the prestimulus period as the baseline. Three ROIs of interest were defined based on the grand average evoked responses: frontal, central, and occipital.

Preliminary results show a differential response only during the test phase in the central ROI toward the shape in trials with low vs. high probability at the category level, while maintaining equal



probability at the item level (Figure 2). Since it is impossible to predict the upcoming shape if probabilities are encoded at the item level, these results suggest that while 5-month-old infants might first encode associations' probability at the item level, consolidation leads to encoding associations at the category level, thus to overgeneralisation, and possibly to the formation of condensed representation. Future analysis will examine changes in the animal's neural representation between the two phases and the role of napping in the consolidation process.

Symposium 3.3 - Vocal agency in social and communicative development

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Summary

How do infant vocalisations and social contingency support vocal learning? We show that early exchanges shape vocal learning, with infants as active agents. Across diverse populations, experiments, observations, corpus analyses, longitudinal designs and cross-species comparisons, we show infants' sensitivity to contingency and culture-specific pathways in vocal agency. Infants and caregivers also respond to specific acoustic features in each other's vocalisations, indicating bidirectional contingency. Humans and zebra finches, though evolutionarily distinct, use their voices to guide the temporal dynamics of syllable sequences. Ultimately, infants not only detect external responses but hold predictive control over the sensory feedback of their own voice. We examine how it relates to how often they vocalise, how much contingent feedback they receive, and the complexity of their productions. Together, we discuss how vocal agency, contingency and vocal practice shape early speech.

Details

Abstract 1, Title: The origins of vocal communication: Culture-specific developmental pathways and social contingency mechanisms

Abstract 1, Text: A key milestone in early communicative development is infants' growing understanding that their own vocalisations can elicit responses from others. This awareness is likely associated with an emerging sense of agency: the experience of exerting control over one's vocalisations and their social consequences. Although social contingency—caregivers' timely responses to infants' behaviour—is widely assumed to play a crucial role in this process, little is known about how infants learn the social efficacy of vocalising across cultural contexts that prioritise proximal versus distal parenting styles. Furthermore, it remains unclear which social contingency mechanisms support this process.

Study 1 assessed culture-specific developmental pathways in the emerging sense of agency over vocalisations. It employed the still-face paradigm at 3 and 4.5 months of age in two cultural groups (N = 47): a proximal-care, Indigenous-heritage Kichwa community in the Northern Andes, rural Ecuador, and a distal-care, middle-class sample from Münster, urban Germany. The vocal



extinction burst, defined as an increase in the relative frequency of non-cry vocalisations during the still-face episode relative to baseline, was used as an index of infants' emerging sense of agency over their vocalisations. A larger vocal extinction burst was expected in the Münster sample at 4.5 months. Contrary to predictions, 4.5-month-old infants did not yet exhibit a clear vocal extinction burst in either culture (Figure 1). However, 4.5-month-old German infants showed a trend in this direction and vocalised significantly more overall than Kichwa infants. Furthermore, their vocalisation duration increased significantly during the still-face episode relative to baseline. When assessing developmental pathways from 3 to 4.5 months of age using an individual-level index of the vocal extinction burst, both cultures showed limited individual-order stability.

Study 2 examined the role of contingent vocal imitation in the emerging sense of agency over vocalisations using a novel vocal-contingency paradigm. We investigated whether 5- to 6-month-old infants from urban Germany ($N = 30$) could rapidly learn the contingency between their own vocalisations and a novel imitative response, and whether they tested this newly learned contingency when it was suddenly discontinued. Novel audio-visual imitative responses were delivered and manipulated by an artificial agent (i.e., a plush chatter-monkey). Infants' vocalisations were recorded while they experienced the novel contingency (connect phase) and its discontinuation (disconnect phase). We hypothesised that, if infants quickly learn this association, their vocalisation frequency should increase linearly during the connect phase. If infants subsequently test this newly learned contingency upon experiencing its discontinuation, we should observe a quadratic trend (i.e., rise-and-fall pattern) in vocalisation frequency during the disconnect phase. There was a significant linear increase in vocalisation frequency over time in the connect phase, supporting the hypothesis that contingent vocal imitation enables rapid vocal contingency learning (Figure 2). Data suggested a quadratic trend during the disconnect phase. However, this trend did not reach statistical significance.

Together, these findings point to culture-specific pathways in a foundational aspect of vocal development and highlight the need for further research to clarify the underlying social contingency mechanisms.

Abstract 2, Title: Beyond temporal contingency: The acoustic and pragmatic features of caregiver responses that predict infant vocal engagement

Abstract 2, Text: Bidirectional contingency in infant–caregiver interaction is instrumental in shaping the development of turn-taking and the selective reinforcement of speech-like infant vocalisations (Warlaumont et al., 2014; Gros-Louis & Miller, 2018). Caregivers simplify their speech in response to infant vocalisations (Elmlinger, Levy, & Goldstein, 2025) and the exaggerated pitch contours of child-directed speech support infant attention and learning (Nencheva et al., 2020). Yet, the acoustic and pragmatic profile of caregiver responses that may be instrumental in eliciting infant contingent responses remain understudied.

We analysed 262 daylong home recordings of 119 mother-infant dyads (4-30 months).



Vocalisations were automatically identified and infant vocalisations classified as canonical, non-canonical, cry or laugh. Pitch, pitch variation, intensity, cepstral peak prominence and duration were extracted from infant and maternal vocalisations, while the latter were also automatically transcribed and classified as questions, declaratives, imperatives and single-word utterances. Contingent responses were vocalisations following the previous speaker within two seconds (Fig 1A).

Compared to non-contingent caregiver speech, contingent responses were higher-pitched, more pitch variable, louder, shorter, more harmonic, and more likely to be single words and questions (Fig 1C). We then tested which caregiver features predicted whether infants would respond in turn (Figure 2). Infants were more likely to respond when caregivers produced shorter ($OR = 0.85$, $p < 0.001$), more harmonic vocalisations ($OR = 1.09$, $p < 0.001$) closer in pitch to the infant's preceding vocalisation ($OR = 1.06$, $p < 0.01$). Declaratives were less likely to receive infant responses ($OR = 0.81$, $p < 0.05$) while single-word utterances were more likely ($OR = 1.17$, $p < 0.05$). These findings suggest that beyond temporal contingency, specific vocal characteristics of caregiver responses may be instrumental in sustaining turn-taking exchanges crucial to vocal development.

Abstract 3, Title: The social origins of vocal sequence learning in songbirds and human infants

Abstract 3, Text: From birdsong to human language, acoustic communication by vocal learners involves concatenation of sounds into sequences. Sequences are more efficient for the producer and more accommodating to the capacities of receivers. Over development, compression of syllables into rapid sequences (more syllables per second) may reflect both social learning and motor maturation. Social feedback guides several acoustic features in the vocal development of humans and songbirds. Might it also guide the sequential structure of vocal forms?

In study 1, 50 caregiver-infant dyads participated in 15-minute free-play sessions in the lab. Caregivers were asked to play as they would at home. Audio-visual recordings of infants' vocalizations and caregivers' speech during free play were obtained. These 10-month-old infants' ($M=9.70$) vocalizations were categorized as vocal sequences if multiple syllables were produced with less than 1 second of pause in between syllables. For each infant vocalization, we determined whether it elicited a caregiver response. Caregiver responses were defined as any verbal behavior which occurred within 2 seconds after infants' vocalizations.

In study 2, 30 caregiver-infant dyads participated when infants were 5 ($M=5.32$) and 10 months of age ($M=9.74$). Dyads engaged in 15-minute unstructured free-play sessions. Caregivers completed the Communicative Development Inventory (CDI): Words and Gestures when infants were 18 months old to assess infants' word production (Fenson et al., 1994). In study 3, 9 juvenile zebra finches were raised by their parents until 35 days post-hatch (dph) and thus had access to their father's (i.e., tutor's) song during their sensory song memorization phase. Juveniles then received video playback responses to their song (1 hour/day) from 35-60 dph. During the playback sessions, each time the bird sang an experimenter triggered video of an adult female appearing to "fluff-up". Fluff-ups are elicited by complex, attractive song (Vyas, et al., 2009). Songs were recorded and



assessed at 45 and 90 dph for syllable rate and acoustic similarity to tutor (Tchernichovski, et al., 2000).

In Study 1, we found that (1) human infants' vocal sequences strongly engage their caregivers (Figure 1), and in Study 2 (2) social feedback to 5-month-old's sequences predicted sequence compression over development (Figure 2A), and (3) sequence compression over development predicted infants' vocabulary development (Figure 2B). Similarly in Study 3 on zebra finch (*Taeniopygia guttata*), we found that (1) early social feedback predicted finches' sequence compression (Figure 2C) and (2) compression only predicted song maturity (similarity to tutor) when birds received contingent social feedback to their immature vocalizing (Figure 2D).

Socially guided vocal learning is a crucial learning mechanism of vocal development, with strong parallels across humans and songbirds (Carouso-Peck & Goldstein, 2019). Previous research on feedback to early vocal learners has focused mainly at the level of individual syllables. Our findings point to a parallel socially-guided learning mechanism of sequential vocal forms as well. The ability to change the immediate learning environment by producing early immature behavior guides vocal development across two distantly related species. Thus, our study provides evidence of a shared social mechanism for vocal development in both songbirds and humans.

Abstract 4, Title: The role of vocal experience and parental contingency on infant vocal self-recognition and communicative development

Abstract 4, Text: Most infants vocalise from birth. However, how they come to predict the sensory consequences of their vocalisations and ultimately use them intentionally to communicate remains unclear. We have three objectives: a) to chart the developmental trajectory of vocal self-recognition, inferred from the ability to monitor one's own vocal output based on predictive internal forward models (Choi et al., 2023; Guenther & Vladusich, 2012); b) to examine how vocal practice supports vocal self-recognition and phonological development, and how these three variables interrelate; c) to assess the role of caregiver contingency in this process.

Study 1 used an altered auditory feedback (AAF) paradigm (Burnett et al., 1998; Parkinson et al., 2013; Subramaniam et al., 2018; Goupil et al., 2021), with 48 French 5-month-olds (Mage = 5.03). We digitally modified infants' perceived pitch by shifting it upwards or downwards, while they interacted with their caregivers. Infants responded to the pitch modifications by adjusting their produced fundamental frequency in the opposite direction, correcting for the change (Figure 1). This early predictive control suggests that routinely hearing ourselves from birth allows us to build a sense of what we sound like, months before we recognise what we look like (Amsterdam, 1972). We hypothesized that vocal self-recognition would strengthen with age, as vocal practice might reinforce infants' internal model of their voice; unexpectedly, no age effect emerged.

Study 2 is a longitudinal follow-up combining AAF and home recordings at 4 months (T1) and 7.5 months (T2). We measure parental contingency, infant volubility and vocalisation types produced



at T1 and T2. Figure 2 summarises the hypothesised developmental pathways. First, we assess vocal self-recognition stability, by testing whether vocal self-recognition at T1 predicts it at T2. Second, we examine the role of vocal practice: we predict that greater volubility provides infants with sensorimotor experience that feeds their internal forward models, therefore predicting vocal self-recognition cross-sectionally and longitudinally. Both volubility and vocal self-recognition are expected to predict the production of more advanced phonological forms at T2, including supraglottal consonants and canonical babbling that form the foundation of early word production (McCune & Vihman, 2001; Vihman et al., 2015). Third, drawing on theories of social selection and ritualisation (Ghazanfar & Zhang, 2016; Scott-Phillips, 2015), we test whether infants' participation in contingent exchanges supports volubility and, in turn, vocal self-recognition and phonological development. Specifically, we examine whether caregiver contingency at T1 predicts volubility at T1 and T2, indirectly predicting vocal self-recognition at both time points and phonological development at T2. Study 2 is pre-registered and involves infants growing up in predominantly French-speaking households in France, from a relatively heterogeneous social and ethnic background. Data collection is underway: the pre-registered sample size for this study is 50 (<https://osf.io/gv576/overview>), and data from 20 infants have already been collected. We anticipate having sufficient data to present by July 2026.

Together, the studies help determine when infants first recognise their vocal behaviour as their own, how this awareness emerges from sensorimotor and social experience, and how it supports further intentional communication and speech.

Symposium 3.4 - Infants in unpredictable contexts: environmental, physiological, and behavioral influences on early development

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Summary

Unpredictability refers to irregular, hard-to-anticipate pattern and events in infants' environments. It may be characterized in caregiving, household, and ecological contexts and unfold over timescales from moment-to-moment interactions to longer-term instability. It is proposed that early sensitive periods require structured input for neurodevelopment and that unpredictability can profoundly impact developmental trajectories. The four studies in this symposium examine unpredictability across multiple levels: neighborhood and socioeconomic conditions influencing parental sensory signals, physiological-linguistic coupling to variable semantic predictability, longitudinal links between maternal unpredictability and toddlers' socioemotional outcomes in a Ugandan cohort, and infants' vocal responses to fluctuating home noise. Collectively, these studies show converging evidence that unpredictability operates through diverse channels, stressing its central role in early development.

Details

Abstract 1



The Role of the Environmental Context on Unpredictable Parenting

Background

Exposure to unpredictable environments early in life conveys risk for poor health and developmental outcomes. Patterns of sensory input from the parent in the first years of life is essential not only for the maturation of sensory neural circuits but for cognitive and emotional circuits as well. Accumulating evidence from our group and others shows that unpredictable parenting indexed by maternal sensory signals is related to poorer cognitive performance, altered stress response, physical growth, and internalizing behaviors such as higher fear and anxiety during infancy and childhood. Less is known about how the environmental context influences unpredictable parenting behaviors. We will first review findings documenting effect of unpredictable parenting on child development. Then we will present new data from our project examining environmental factors that contribute to unpredictable parenting. Specifically, we examine household income and neighborhood opportunity as they relate to unpredictable parenting and whether neighborhood opportunities may moderate the effects of household income on unpredictability.

Method

Participants were 173 pregnant individuals ($M_{age}=32$, $SD=5.4$ years) and their 6-month-old infants ($M_{age}=6.4$, $SD=0.7$, 56.5% female). During early pregnancy, demographics, income, and residential address were collected. We then calculated household income-to-needs ratio (INR) as a socioeconomic measure based on household income and size. We geocoded participant residential addresses to characterize neighborhood opportunity using the Child Opportunity Index (COI). COI scores reflect how much a child can thrive in the census tract in which they live with respect to accessible educational, health, socioeconomic, and environmental resources. When the infants were 6 months old, dyads were invited to the lab for a semi-structured mother-infant interaction task. The unpredictability of maternal sensory signals was then coded from video using a validated coding scheme that characterizes auditory, tactile, and visual inputs from mother to infant, consistent with prior literature. Finally, the entropy rate was computed as a measure of the rate of unpredictability in the transitions among sensory states. Regression analyses examined associations between INR, neighborhood opportunity, and unpredictability of maternal sensory signals. Next, we examined whether neighborhood context moderates the association between INR and unpredictability of maternal sensory signals.

Results

Neighborhood opportunity and INR were not independently associated with unpredictable maternal sensory signals ($ps > .05$). However, INR moderated associations between neighborhood opportunity and unpredictability of maternal sensory signals ($b=0.0004$, $SE=0.0002$, $p=0.24$) such that lower neighborhood opportunity was associated with greater unpredictability of maternal



sensory signals only for those at lower levels of INR.

Conclusion

Unpredictable parenting has important implications for child neurodevelopment. Current findings suggest that environmental context can play a role in shaping unpredictable parenting. A combination of living in a neighborhood with low opportunity and having low household income could lead to higher levels of unpredictability among caregivers. We will discuss the implications of this work in the symposium.

Abstract 2

Developmental Increase in the Coupling between Physiology and Semantic Surprisal in Naturalistic Interactions

Understanding how infants may track and respond to the predictability of language in their everyday environments is crucial for theories of early communication and learning. Prior work suggests that caregivers adapt their linguistic input as infants develop, e.g. using less redundant speech (Tal et al., 2021). However, little is known about the moment-to-moment changes in caregivers' speech predictability, as a function of infant physiological states. Individual differences in how much caregivers attune their linguistic complexity, contingent on infant arousal states (Wass et al., 2022), may provide insight into how behavioural predictability scaffolds development (Davis et al., 2022).

The predictability of forthcoming speech, formally defined as semantic surprisal, has been found to modulate adult brain response to speech (Heilbron et al., 2022), and potentially reflect the cognitive load required to process language (Michaelov et al., 2020; Shain et al., 2024). It has been argued that infants develop this semantic sensitivity over their first year (Friedrich & Friederici, 2017). Accordingly, we hypothesised that, over development, infants would show increased physiological coupling to semantic surprisal.

We examined developmental changes in the coupling between infants' heart rate (HR) and caregivers' semantic surprisal during naturalistic daylong recordings. Infants and caregivers from a socio-economic diverse sample in London were equipped with synchronised wearable audio and physiological sensors at 5 months ($N=31$) and 15 months ($N=16$) (preliminary sample). Using a Voice Type Classifier (Lavechin et al. 2020), we isolated the caregiver's speech and transcribed it at the word level using WhisperX. We then computed the semantic surprisal of each word as the log probability of the upcoming word, obtained using the word-level prediction made by a GPT-2 model, and considering the previous context (Willems et al., 2016; Peñaherrera et al., 2025).

We first examined age-related changes in caregivers' linguistic predictability, expecting higher averaged semantic surprisal overheard by 15-month-olds, than by 5-month-olds, driven by caregivers using increasingly variable language when interacting with the older infants. However, preliminary results did not reveal that caregiver speech to older infants was more surprising than for younger infants ($t=1.57$, $p=0.12$, Fig. a). We then performed cross-correlation analyses between the infants' HR time series and semantic surprisal, assessing temporal dynamics of physiological-linguistic coupling. A cluster-based permutation analysis on the cross-correlations revealed



significant increases between coupling from 5- to 15-month (Fig. b). A positive correlation at negative lags (around -10s) was found, indicating that infant HR preceded the caregiver's semantic surprisal.

These methods demonstrate the feasibility of using wearable devices and machine learning-based language modelling to study the fine-grained dynamics of caregiver predictability, and how it's modulated by infant states, in real-world settings. Whilst the results suggest there was no difference in average semantic surprisal between age points, they do point towards increased coupling of infant physiology and caregiver linguistic complexity over the first year of life.

Abstract 3

From Infancy to Toddlerhood: Maternal Unpredictability and Child Emotional Reactivity in a Southwestern Ugandan Cohort

Unpredictability of maternal sensory signals, referring to inconsistency in moment-to-moment auditory, tactile, and visual input, has emerged as a meaningful dimension of early caregiving. Research, largely from high-income settings, indicates that early exposure to maternal unpredictability is associated with poorer cognitive and socioemotional outcomes. However, little is known about these processes in low-income settings, where caregiving conditions and environmental stressors may have a large impact on environmental predictability. In our previous work with a Ugandan cohort, greater maternal unpredictability in infancy was linked to reduced negative emotional reactivity ($\beta = -.22$, $t(113) = -2.40$, $p = .018$; Garzón et al., in press). Whether these early patterns remain developmentally relevant as children enter toddlerhood, when emotional competencies and regulatory demands increase markedly, remains underexplored. This follow-up study examines two central questions: (1) whether maternal unpredictability shows stability across this developmental period, and (2) whether unpredictability in infancy prospectively predicts toddlers' emotional reactivity in a high-adversity context.

This longitudinal study followed 115 mother-child dyads from Southwestern Uganda, assessed at 7-9 months (Time 1; T1) and again at 24-30 months (Time 2; T2). Maternal unpredictability at both time points was derived from video-recorded free-play interactions. Unpredictability was quantified using entropy rate, calculated from transitions among maternal auditory, tactile, and visual sensory signals modeled as a first-order Markov process, with higher values indicating greater unpredictability (Davis et al., 2017). At T2, children's emotional reactivity was assessed using an adapted Still-Face Paradigm for toddlers and coded for duration, intensity, and latency of negative affect. Mothers completed the Center for Epidemiologic Studies Depression Scale to account for maternal depressive symptoms as a potential covariate. Mixed-effects models will test longitudinal associations between maternal unpredictability and child outcomes, as well as the consistency of maternal unpredictability across early development.

Guided by our previous findings, we expect that greater maternal unpredictability in infancy will



predict lower negative emotional reactivity in toddlerhood. We also anticipate an association between unpredictability at T1 and T2. Findings will be presented at the symposium.

This study will provide new prospective evidence on whether early exposure to unpredictable maternal sensory signals continues to shape socioemotional functioning as children transition into toddlerhood, and whether maternal unpredictability itself remains stable across this developmental period. By examining these processes in an understudied, high-adversity context and tracking the same cohort over time, the study advances a more global and nuanced understanding of how early caregiving patterns shape developmental trajectories.

Abstract 4

Listening for Quiet: Infant Self-Initiated Vocalisations as Compensatory Responses to Decreasing Auditory Environmental Stimulation

Infants engage in active self-regulation by dynamically adjusting their behaviour in response to fluctuations in environmental stimulation (Wass et al., 2024). Recent evidence shows that at home, mothers' and infants' vocalisations decrease when background sound categories (e.g., television, appliances, transportation) increase, suggesting cascading influences from ambient auditory conditions on caregiver–infant behaviour (Suarez-Rivera et al., 2024). One interpretation is that infants employ a form of negative feedback: when external stimulation drops, their own output increases (e.g., vocalisations) to modulate arousal or re-engage with their surroundings (Wass et al., 2024). However, these processes have not been examined using fine-grained acoustic features from naturalistic home environments or tested for developmental changes.

We hypothesised that infants would be more likely to produce self-initiated vocalisations during periods of decreasing background-noise amplitude envelope, and that infants living in more chaotic households would experience higher-amplitude background noise. We further expected these associations to remain consistent across developmental stages.

We collected infant-worn microphone data from day-long recordings in naturalistic home settings at 5, 10, 15, and 30 months of age. The 48kHz audio recordings were processed using an open-source speaker-diarisation model (Voice Type Classifier; Lavechin et al., 2020) to identify infant and maternal vocalisations. Self-initiated canonical vocalisations were extracted by isolating time windows in which infants vocalised without their caregiver having been vocal for >2 seconds, consistent with contingency definitions in social-interaction literature (Chang et al., 2017). The amplitude envelope of the home acoustic environment was computed directly from the raw audio signal to track moment-to-moment fluctuations in background noise, excluding the times when infants vocalised in the 2 seconds preceding each onset. Families completed the CHAOS questionnaire to assess home-environment chaos. Time-locked analyses of the amplitude envelope were conducted for the 2 seconds preceding and 250ms following vocalisation onset;



surrogate baselines were constructed from randomly sampled moments, and cluster-based permutation analyses assessed significance (Figure 1).

Preliminary analyses of the 5- and 15-month datasets ($N_{\text{infant_5m}} = 92$, $N_{\text{infant_15m}} = 51$; $N_{\text{vocalisations_5m}} = 98,906$; $N_{\text{vocalisations_15m}} = 61,968$) indicate that infants, regardless of age, tend to self-initiate vocalisations during periods of declining amplitude envelope. Households of 5-month-olds showed higher overall amplitude envelopes than those of 15-month-olds. The envelope 2 seconds before onset was higher than baseline but began to decline ~500ms before the infant vocalised, ultimately falling below baseline prior to onset. Permutation tests confirmed these effects. A linear mixed-effects model showed that higher CHAOS scores predicted higher background-noise amplitude ($R^2 = .15$, $p = .04$). Ongoing analyses will extend these findings to the four age groups to present at the symposium.

These results support early self-regulation models (Porges, 2023; Aston-Jones & Cohen, 2005), demonstrating that infants adjust behaviour on fine temporal scales in response to shifting environmental stimulation. Findings underscore the developmental importance of auditory environments: noisier homes may reduce opportunities for language exploration and social engagement (McDaniel & Radesky, 2018) and create less predictable soundscapes that can affect attention and cognition (Werchan et al., 2022).

Symposium 3.5 - 'Wild with emotion': new frontiers in understanding the contextualized emotion processing development in infancy

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Summary

The study of infant emotion processing development is undergoing a paradigm shift, from simplified laboratory tasks to the dynamic, multimodal complexity of the real world. This symposium presents a transformative view to tackle the contextualized emotion processing development in the 'wild'. We show how motor development transforms infants' emotional landscape. Big-data analyses of egocentric videos reveal that early emotion input contains distributed linguistic and contextual cues. Multimodal sensing shows how infants' physiology and cognitive states become tuned to the contextualized natural social input. Finally, we examine the socialization of self-conscious emotions, revealing distinct stability patterns in negotiating shame and pride. Collectively, these findings represent a decisive shift towards bridging ecological reality and affective science for unprecedented understanding of early emotion processing development.

Details

Abstract 1



Title: From motion to emotion: Cascades from motor milestones to emotional input

Text: According to developmental cascades theories, changes in the motor domain can have downstream effects on one or more other developmental domains (Oakes & Rakison, 2019). Indeed, every new motor posture changes an infant's perspective. When an infant can sit independently, they can see the entire room, with hands free to manipulate objects. When infants begin to crawl, they gain the ability to move around the room independently for the first time, but their field of view while moving is limited and hands occupied. Finally, when they begin to walk, they can see the entire room again, while moving around it independently, with hands free to carry objects.

Here, we ask whether the onset of new locomotor skills changes infants' exposure to emotional information. We explored differences in parents' emotional input before and after the onset of three important motor milestones—independent sitting, crawling, and walking. We coded hour-long naturalistic videos of 44 infants (21 female, 42 White) from the SEEDLingS dataset collected longitudinally at 4 time points (6–8 months, 9–11 months, 12–14 months, and 15–17 months). Speech was transcribed and processed with LIWC to derive linguistic emotional input (i.e., % of emotion words used, % positive, % negative), and video data were coded for presence of a face and subsequently FACS coded for stereotyped emotional facial configurations. Parent report of infants' motor skill was used to determine onset of each skill of interest.

Paired-sample t-tests compared variables pre- and post-onset of each milestone. Following the onset of sitting, parents spoke fewer words when compared to the prior timepoint, $t(23) = 4.54$, $p < .001$, $d = 0.93$. A similar pattern was found for the onset of crawling, $t(27) = 4.44$, $p < .001$, $d = 0.84$. For walking, though there was no significant difference in number of words spoken to infants overall, the proportion of emotion words parents produced decreased following onset of walking relative to before, $t(21) = 2.12$, $p = .046$, $d = 0.453$. Children also saw more negative facial configurations after the onset of crawling when compared to the previous timepoint ($M = 0.25$, $SD = 0.062$), $t(27) = 2.21$, $p = .036$, $d = 0.42$ —consistent with predictions from prior literature (Campos et al., 2000). Finally, infants saw fewer full-view faces after the onset of walking when compared to the previous timepoint, $t(22) = 2.13$, $p = .045$, $d = 0.443$.

These findings suggest that transitions in locomotor development are related to changes in infants' exposure to emotional input. Reduced language from caregivers after each motor milestone could be indicative of infants' increasing independence. The increased presence of negative facial configurations following crawling may reflect parents' increased use of prohibitory or cautionary signals as infants begin to explore their surroundings more independently. And finally, reduced availability of full facial information following onset of walking may reflect infants' growing focus on broader physical environments. Altogether, this investigation marks an early foray into the empirical study of motor development cascading into changes in infants' emotional environments.

Abstract 2

Title: Linguistic emotion information in everyday activity contexts

Text: Linguistic and contextual cues have been theorized to be the building blocks of early emotion understanding (Hoemann et al., 2019). Here, we apply computational annotation tools to a large



longitudinal egocentric video corpus (BabyView; 885 hours; 5–36 months; N=31; Long et al., 2024; 2025; Sepuri et al., 2025) to examine how common emotion language is in the home, and how it unfolds across one of the salient contextual features of early experience - infants' everyday activities and routines.

How often do children encounter emotion language? We transcribed videos using Whisper (Radford et al., 2022) and classified each utterance into emotion categories (joy, surprise, sadness, anger, and fear), using bert-base-uncased-emotion (an open-source classifier; Savani, 2024). Using these labels, we tagged the presence of each emotion in 10-second video segments. In 500 manually-validated utterances, the classifier yielded moderately high precision (78%) and recall (74%). Linguistic expressions of emotion were very prevalent (Figure 1a); joy was most common (39.2% of clips), followed by anger (8.9%), fear (4.3%), sadness (1.8%) and surprise (0.3%). Therefore, supporting prior theoretical accounts (Hoemann et al., 2019), linguistic emotion cues are a readily available signal for learning about emotion.

Can the activities (e.g., playing, eating a meal or reading a book with a caregiver) surrounding emotion language provide an additional signal that can help infants learn about emotions? We used activity annotations generated by Sepuri et al., 2025, who prompted a VideoQA model to extract the primary activity present in each 10-second video clip using a list of common activities in infancy (e.g., mealtime, storytime). We quantified the association between each activity and emotion as normalized pointwise mutual information (NPMI; Figure 2c). Joy was most prevalent during play. Sadness was most common during cleaning, including moments of grooming (while brushing the child's teeth, "I'm sorry, I know your teeth hurt, but we still gotta brush!"). Fear was most commonly referenced during book reading (discussing a character in a book, "Little Blue looks scared!"). Anger was most common during mealtime ("You're getting mad but you keep throwing it!").

How similar were the activity contexts across positive and negative emotions? We computed cosine similarity between the NPMI scores for each emotion-activity pair across participants and across emotions. Negative emotions (fear, sadness, and anger) occurred in more similar contexts to each other, vs. to a positive emotion (happiness; $\beta=0.58, p<0.001$; Figure 2b). Although they need to be replicated with a wider range of emotion categories, these results provide preliminary evidence that the way emotion language is distributed across home activities can help children form valence-based emotion categories.

Overall, these findings demonstrate how automated language processing and video annotation tools can reveal the real-world linguistic emotion cues infants encounter and highlight the central role of linguistic and contextual information in emotion development.

Abstract 3

Title: Developing Sensitivity to Facial Expressions in the Wild: A Multimodal, Contextualized Egocentric Approach



Text: Infants continuously encounter rich social signals as they move through their everyday environments, yet little is known about how they learn to interpret facial expressions under natural viewing and social interaction conditions. Can infants discriminate among different facial-expression categories as they spontaneously occur in real life? And does sensitivity to these cues follow a developmental sequence? Laboratory-based studies suggest that the first year is critical for the emergence of emotion recognition abilities (e.g., Barrett, 2020; Hoemann et al., 2020; Leppanen & Nelson, 2009), but characterizing how these abilities develop in real-life contexts is challenging due to technological and methodological difficulties in accessing infants' naturalistic visual and physiological experience.

To address this gap we used the EgoActive platform (Geangu et al., 2023), which integrates head-mounted cameras (HMC) with wearable ECG and accelerometer sensors to collect synchronized egocentric visual input, autonomic activity, and movement data from infants aged 6- to 13-months in their home environments (N=59). Recordings were obtained longitudinally across four developmental time points (6-, 9-, 11-, and 13-months). Infants contributed data as follows: 33 - first two time points, 24 - first three time points, and 15 - all four time points. Overall, 1769 hours of data were included in the analyses (1204 continuous recordings, average length = 1.5 hrs).

Facial expressions appearing in the HMC videos were quantified using neural-network models for face detection and facial-expression recognition (Tan & Le, 2019), producing frame-by-frame probabilities for seven canonical expressions (anger, disgust, fear, happiness, neutral, sadness, surprise). These estimates were segmented into discrete facial-expression episodes using a dynamic segmentation algorithm. For each detected face, we also estimated the distance and head orientation using facial landmarks, providing indicators of social proximity and engagement. We identified 10 robust clusters by applying Uniform Manifold and Projection (UMAP) to the combined expression–distance–orientation feature space followed by density-based clustering. These clusters represent distinct social configurations experienced by infants in real-life contexts.

We then assessed infants' responses to these input clusters using synchronized multi-modal measures of autonomic state (heart rate, respiratory sinus arrhythmia), gross motor activity, and attentional state. Attentional states were derived using ASAP, a heart-rate–defined sustained-attention algorithm (Zhang et al., 2025). Linear mixed-effects models revealed significant differences in infants' autonomic, motor, and attentional responses across the 10 social-input clusters (main effect of cluster: $p < .001$). Happy and surprised expressions elicited significantly stronger autonomic and behavioral responses ($p < .001$), whereas responses to neutral expressions varied systematically with distance and orientation.

Finally, representational similarity analyses showed that representational dissimilarity matrices built from social-input features and infant-response measures were positively correlated. This indicates that infants' multisystem responses mirrored the underlying organization of the social facial configurations they experienced. Mixed-effects modeling revealed a developmental increase in this social–physiological representational alignment (main effect of age: $p = .005$), suggesting gradual internalization of the structure of facial-expression cues over infancy.



Together, these findings provide the first ecologically grounded evidence that infants' autonomic and behavioral responses become increasingly tuned to the structure of natural facial-expression input, illuminating how emotional understanding emerges through everyday social interactions.

Abstract 4

Title: Shame on You! The Socialization of Self-Conscious Emotions in Early Childhood

Text: Self-conscious emotions, such as shame, embarrassment, guilt, awe, and pride, play a key role in social behavior (Muris et al., 2014) and emotional well-being (Kealy et al., 2022). Although these emotions may emerge as early as 18 months of age (Tangney et al., 2007), little is known about how they are discussed and socialized from infancy into early childhood. This is a critical developmental period when children are beginning to form a sense of self (Rochat, 2003), so it is important to understand the processes by which they are learning to recognize and interpret complex emotions. As primary caretakers, parents tend to be the main agents of socialization during these early years of life, passing on implicit and explicit messages about emotions to their children (Grusec & Davidov, 2010).

Parent-child dyads ($N = 285$) were observed discussing a wordless picture book depicting self-conscious emotions (shame, guilt, embarrassment, awe, pride) annually for three years starting at age 2. The illustrations in the picture book (see Figure 1) depicted various cartoon children “emoters” expressing discrete emotions through facial expressions and body posture, each in response to a specific context designed to evoke a self-conscious emotion. Emoters' expressions were modeled after well-established research on emotion expression (Keltner et al., 2019). The observed discussions were transcribed and the frequencies of emotion labels used by the parent and the child were coded from transcriptions. Emotion labels were categorized according to the emotion being discussed to allow for a more nuanced analysis of the socialization process underlying each discrete emotion type. To examine the associations between parent and child emotion talk, cross-lagged panel models (CLPM) were estimated for each of the five self-conscious emotions. The models assessed stability, concurrent correlations, and bidirectional cross-lagged effects, providing a comprehensive view of how parents' and children's talk about self-conscious emotions may be linked across three years of infancy and early childhood. Model fit was evaluated using established indices (χ^2 , CFI, RMSEA, SRMR) and structural invariance was confirmed prior to interpreting results.

The results and model fit of all CLPMs are reported in Figure 2. There were significant associations between parent and child emotion talk within all waves for all five emotions with moderate effect sizes (β range = .21 to .41). Modest stability paths emerged for shame across all waves (β s = .14 and .22, p s $\leq .02$), and one small cross-lagged effect was observed for pride ($\beta = -.08$, $p = .04$). No other stability or cross-lagged effects were observed.

These results contrast with extant literature on parent-child emotion talk patterns for basic emotions, which has documented longitudinal associations (Laible et al., 2013; Reschke et al., 2024), suggesting that the socialization of self-conscious emotions may be more nuanced. These findings provide novel insight into how self-conscious emotions are socialized during infancy,



advancing our understanding of social-emotional development during this critical period. Implications for parent socialization processes and applications in practical settings will be discussed.

Symposium 4.1 - Using wearable devices and machine learning for multimodal investigations of infant development in naturalistic contexts

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Summary

This symposium showcases wearable and multimodal methods for studying infant development in naturalistic contexts. The first presentation presents an open-source, head-mounted wearable that enables scalable, long-form egocentric video recordings with integrated ASR and face-detection data processing pipeline. The second uses inertial sensors and ML to detect infant restraint and validating outputs against human annotations to provide precise measures of daily movement. The third combines daylong audio, ECG, and motion recordings to examine how infants' vocalizations decouple from autonomic arousal through caregiver responsiveness. The final presentation benchmarks face detection models and introduce the TinyExplorer Detection App, making ML-assisted annotation more accessible. These talks outline updated methodological pipelines, combining wearables and ML-assisted annotation and analyses, which are advancing scalable, ecologically valid approaches to studying infant development.

Details

Abstract 1, Title: OpenBabyographer: An Open-Source Infant Wearable for Naturalistic Audio-Visual Data Collection

Abstract 1, Text:

Infant-caregiver interactions are foundational for early language, social, and cognitive development (Hart & Risley, 1995; Goldstein & Schwade, 2008; Bakeman & Adamson, 1984). However, most developmental findings are derived from short, structured laboratory paradigms that capture limited and unrepresentative slices of infants' daily lives (Belsky, 1980; Deák et al., 2017). Controlled paradigms often miss spontaneous multimodal cues such as gaze, gesture, prosody, object manipulation, that shape infants' learning (e.g., Deák et al., 2017; Golinkoff et al., 2015). Even with richer naturalistic data, the laboriousness of manual coding constrains most studies to a few variables. Moreover, despite evidence that caregiver input and interaction styles vary widely across cultures (Cristia et al., 2019), most infancy studies draw from WEIRD populations (Henrich et al., 2010), which risks constraining developmental theory. Improving the representativeness of developmental datasets requires tools that reduce financial, labor, and technical barriers, and enable families from diverse backgrounds to participate. Audio-only recorders like LENA (Gilkerson & Richards, 2008) have enabled large-scale naturalistic studies but remain costly, proprietary, and single-modality. Recently, integrated multimodal platforms such as EgoActive (Geangu et al., 2023), LittleBeats™ (Islam et al., 2024), and BabyView (Long et al., 2024) have advanced the field by simultaneously recording audio, video, and/or physiological data in naturalistic settings. These innovations inspire the next generation of accessible infant wearables (Lee et al., 2017).



Building on these efforts, we developed OpenBabyographer, a low-cost, open-source, lightweight head-mounted infant wearable that captures audio and video from an egocentric perspective. Openbabyographer is built around a soft, adjustable head protector housing a Raspberry Pi Zero 2W, dual microphones, and a wide-field-of-view camera.

In this study, we assessed (1) whether the device meets safety and performance requirements (speech intelligibility, temperature control, and battery life), (2) wearability and caregiver satisfaction, and (3) explore whether automated analyses of egocentric audio-video streams reveal meaningful variability in infant–caregiver interaction.

Ten infants (mean age = 12.4 months, range = 4.1 - 24.2 months; 3 female) from nine multilingual families (English, Mandarin, Spanish, Korean, German) participated in home-based sessions (local IRB approved).

Laboratory tests confirmed speech intelligibility up to 1.5 m (Whisper Word Error Rate $\approx$ 6–14%), safe surface temperatures ($< 37.5^\circ\text{C}$), and recording durations of 2.1–3.75 hours. Parents rated the device highly, describing it as lightweight and comfortable, and suggested minor design refinements (e.g., fit options, padding, LED visibility). Automated analyses using YOLOv8 (Jocher et al., 2023) and Whisper across 390 minutes of data revealed between-family variability in face presence (range: 3.6–43.8% of time; mean = 17.5%), and speech activity (29.0–54.8%, mean = 39.9%). Recordings captured extended periods of low engagement, with caregivers performing chores or using phones, highlighting everyday “interaction gaps” invisible from structured laboratory tasks (Barabási, 2005; Belsky, 1980).

OpenBabyographer offers an accessible, open platform for ecologically valid multimodal data collection. By lowering financial and technical barriers and complementing existing systems, it broadens the reach of wearable methods to diverse cultural contexts and supports a more representative, scalable approach to studying infant development.

Abstract 2, Title: How Caregivers Shape Infant Movement: Using Wearables for Real-time Quantification of Infant Restraint

Abstract 1, Text:

Understanding infants’ motor development requires accurate measurement of their real-world opportunities for movement. These opportunities are shaped largely by caregivers, who commonly restrain infants during daily routines. Although restraint provides safety and comfort, it also limits movement and exploration. Presumably, as infants age, caregivers would restrain infants less often and provide longer unrestrained bouts for sustained exploration. However, no prior work has precisely quantified infants’ overall restraint time and how it is distributed throughout the day. Existing approaches have clear trade-offs: parent-report surveys (e.g., Abbott & Bartlett, 2001; Franchak, 2019; Karasik et al., 2018) capture full-day activities but lack precision, whereas video coding and human annotation (Springfield & Lee, 2025; Wang et al., 2025) provides temporal details but is obtrusive and labor-intensive. We propose that a wearable-sensor and machine-learning system can detect infant daily restraint with high temporal precision over long durations.

We customized a special infant garment to secure four lightweight wearable inertial sensors at hips and ankles to record infants’ real-time body movement. During the home study, caregivers were instructed over the phone to put the garment on infants from morning until bedtime. Nap periods and times when the garment was removed were excluded. An action camera recorded synchronized third-person videos of infant behaviors for the first 1.5 hours of each session. We collected 142 sessions in total (M usable time = 5.87 hours) from 65 infants from two cohorts



(younger 4–7 months; older 11–14 months). Coders annotated videos to provide ground truth labels about whether infants were restrained or unrestrained. Restraint was defined as when infants could not initiate or control their movements (e.g., being held by caregivers or restrained in devices). As in previous studies (e.g., Franchak et al., 2024), we aggregated the raw sensor data into motion features in 4-s windows throughout the day. Tested by a leave-one-out cross-validation procedure, the model achieved high accuracy (87%) and substantial kappa agreement ($\kappa = .70$). Moreover, the model was highly correlated with human annotation for mean restrained bout duration ($r = .94$) and unrestrained bout duration ($r = .91$) at the session level.

We then applied the validated model to full-day recordings to characterize infants' restraint experience in the context of home life. Replicating prior survey-based work (Carson et al., 2022), we found older infants were restrained for a smaller percentage of awake time ($M = 51\%$) than younger infants ($M = 32\%$; $p < .001$). Older infants also experienced longer unrestrained bouts ($M = 1.81$ min) than younger infants ($M = 0.92$ min, $p < .001$). However, the changes only emerged between the two age groups. When age in months was examined within each cohort, there were no month-to-month changes ($ps \geq .49$). This pattern suggests that caregivers might adjust restraint practices around major developmental transitions (e.g., onset of mobility), rather than gradually every month.

In sum, this work introduces the first scalable method for quantifying infants' full-day restraint with bout-level resolution. It opens up new avenues for studying how caregivers shape infants' everyday opportunities for movement and exploration.

Abstract 3, Title: The Decoupling of Physiological Arousal and Vocalisation Across Early Development

Abstract 3, Text:

Even from the first days of life, infants are remarkably vocally active, producing not only cries but also voiced speech-like sounds called protophones (Oller et al., 2021). These early vocalisations may be initiated by fluctuations in autonomic arousal (Wass et al., 2022), providing a developmental scaffold that facilitates the acquisition of volitional vocal control through sensorimotor experience and interactions with caregivers. How infant vocalisations transition from reflexive to intentionally produced remains poorly understood, as laboratory studies cannot capture the natural fluctuations in arousal and caregiver responsiveness that occur across daily life.

We collected daylong home recordings from 92 infants, aged 4 to 21 months, and their mothers, using bespoke wearable devices which recorded audio, ECG, and accelerometer data. We used machine learning to identify ~67,000 infant vocalisations, classified them as cries and non-cries, and examined the relationship between vocalisation and heart rate. We investigated arousal–vocal coupling in two ways: by analysing how arousal discriminates the timing of vocalisations, and by studying its covariation with vocal acoustics. We hypothesised that cries, being fixed signals, would remain strongly coupled to arousal whereas non-cries would become progressively decoupled over development.

Early vocalisations occurred predominantly at heightened levels of autonomic arousal, but this coupling weakened progressively with age. Daylong heart rate time series predicted vocalisation



timing above chance (ROC AUC = 0.64; Fig 1A), and hierarchical linear mixed effects modeling confirmed a developmental decoupling ($\beta = -0.034$, $p < 0.001$; Fig 1B). Arousal also strongly associated with the acoustic features of both cry and non-cry vocalisations, with higher arousal linked to higher pitch ($\beta = 0.182$, $p < 0.001$), increasing harmonicity ($\beta = 0.144$, $p < 0.001$), and longer duration ($\beta = 0.091$, $p < 0.001$).

Crucially, the influence of arousal on acoustic properties showed divergent developmental trajectories for different vocalisation types. For non-cry vocalisations, arousal's association with pitch, pitch variation, and harmonicity diminished significantly with age ($\beta = -0.005$, $p = 0.001$; $\beta = -0.004$, $p = 0.005$; and $\beta = -0.014$, $p < 0.001$, respectively), suggesting infants' increasing volitional control over these speech precursors. In contrast, the arousal–acoustic relationship for cries showed contrasting changes, with features such as intensity and duration ($\beta = 0.064$, $p = 0.021$ and $\beta = 0.025$; $p < 0.001$, respectively) strengthening their coupling over development. This differential pattern suggests the emergence of parallel vocal pathways: one remaining tied to physiological state for fixed affective signals such as cries, and another increasingly decoupled from internal states for the functionally flexible signals critical to speech communication.

Importantly, infants whose caregivers responded contingently to a greater proportion of non-cry vocalizations showed significantly weaker coupling in both temporal and acoustic dimensions ($\beta = -0.034$, $p < 0.001$ and $\beta = -0.198$, $p = 0.044$; Fig 1C). This finding suggests that caregiver responsivity may play a crucial role in accelerating the transition from reflexive, arousal-initiated productions to more volitionally controlled vocalisations. These results clarify the developmental trajectory toward intentional communication and demonstrate the critical importance of ecologically valid, multimodal longform data in combination with automated methods to reveal patterns in everyday infant–caregiver exchanges that may not be identifiable in lab-recorded snapshots.

Abstract 4, Title: Making Machine Learning Accessible for Developmental Science: The Case of Automated Face Detection

Abstract 4, Text:

Recent years have seen rapid advancements in machine learning, significantly transforming fields like cybersecurity and healthcare. Developmental science has been slower to adopt these technologies. Yet, machine learning holds immense potential to transform this field, enabling scalable and data-driven insights into developmental processes. Broader adoption is currently hindered by challenges in (1) *algorithm selection*; and (2) *technical implementation*. We address these barriers by focusing on an area that has reached high sophistication from a machine learning perspective while also being of significant interest to developmental scientists: *face detection*. Face detection is crucial for analysing visual experiences through children's dynamic, first-person views. Automatising this process allows efficient handling of large egocentric datasets, enabling well-powered studies otherwise limited by labour-intensive manual annotation.

Firstly, to address the barrier of *algorithm selection*, we systematically evaluated 13 state-of-the-art face detection algorithms (DeepFace library) using data from two increasingly common developmental methodologies (Figure 1) involving children under three years of age: *head-mounted eye-tracking* (HMET) in more structured settings ($N = 20$; $n = 10$ 4-month-olds; $n = 10$ 8-month-olds) and *head-mounted cameras* (headcams) in naturalistic home environments ($N = 10$ 18–29-month-olds). Benchmarking these algorithms against manual annotations (Figure 2) revealed that *YOLOv11Face (M)* and *RetinaFace* consistently outperformed others in terms of precision and



recall, exhibiting strong concordance with manual ratings, lower error, reduced bias, and robust rank-order correlations with manual annotations.

Secondly, to remove the barrier of *technical implementation*, we introduce an accessible face detection tool (*TinyExplorer Detection App*), promoting efficiency, scalability, and innovation in developmental science by widening access to machine learning. *TinyExplorer Detection App* integrates multiple open-source face detection models, including *YOLOv11 (M)* and *RetinaFace*, each optimised for different computational constraints and accuracy requirements. Users can select from lightweight models suitable for real-time processing to high-accuracy models designed for offline batch processing, allowing researchers to balance detection precision with available computational resources. Crucially, local processing ensures that footage remains on the researcher's machine, avoiding external transfer or cloud storage and helping to protect participant confidentiality. All models in our app run on standard laptops without requiring a discrete GPU. Benchmarking on a MacBook Pro (Apple M1 Max, 32 GB; macOS 14) using a random sample of 5,000 Caltech-101 images (Li et al., 2022) yielded 11.17 images per second for *YOLOv11Face (M)* and 1.12 images per second for *RetinaFace*.

By offering both concrete evaluation data and the *TinyExplorer Detection App*, we aim to empower developmental scientists to embrace these technologies, fostering more comprehensive and data-rich explorations of early development. Our results confirm that while automated detection is not flawless, it is sufficiently accurate to significantly streamline research workflows. Ultimately, integrating automated face detection into standard developmental methodologies will open new opportunities to investigate children's real-world social experiences on a scale and depth that manual annotation alone could not realistically achieve.

Symposium 4.2 - Multimodal and multi-scale dynamics in early infant-caregiver interactions

Grace Steffen¹, Jennifer Somers², Eliala Alice Salvadori³, Pierre Labendzki⁴

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Summary

Researchers have long posited that infant-caregiver interactions are nonlinear and not confined to a single channel, but only recently have analytic advances enabled direct tests. High-density, time-resolved methods now show that interactions are multimodal, multi-scale, and governed by complex temporal dependencies. Using dynamic structural equation modeling, wavelet coherence, information-theoretic time series, and multilevel time-to-event models, recent work demonstrates that moment-to-moment patterns of facial affect, gaze, touch, vocal affect, RSA, and semantic signaling are interdependent and vary by context and timescale. Key findings include: 1) maternal facial stability and lower infant affective volatility predict later child internalizing; 2) RSA synchrony shows context- and timescale-dependent leader-follower shifts; 3) mothers dynamically modulate input to support infant attention; and 4) infants decouple smile from gazing at interaction partners across the first year.

Details



Abstract 1 Title: Four-Month Mother-Infant Self- and Interactive Contingency and Four-Year Child Internalizing Problems and Maternal Depression and Anxiety

Early caregiving experiences play a critical role in shaping subsequent psychopathology (Feldman, 2007, 2015). We evaluated whether self- and interactive contingency in 4-month mother-infant face-to-face communication are associated with 4-year child internalizing problems and emotion dysregulation and mother depression and anxiety. We used Dynamic Structural Equation Modeling (DSEM), testing whether 4-month contingency processes predict 4-year outcomes, over and above 4-month maternal depression/anxiety.

Method

58 Turkish mothers participated in a longitudinal study. At 4 months, mothers were evaluated for clinically-significant depression (Center for Epidemiologic Studies Depression Scale: CES-D, 16+) and anxiety (State-Trait Anxiety Inventory: STAI, 43+). Videotaped face-to-face interactions were coded on a 1s time base for infant (I) and mother (M) gaze and facial-affect, infant vocal-affect (VocA), and M-touch (Tch) (Kahya et al., 2023) during a 2.5-min videorecorded free play. At child 3-to-4 years, mothers completed (via internet) the CES-D and STAI and reported on child internalizing problems (Strengths and Difficulties Questionnaire; Croft et al. 2015) and emotion dysregulation (The Emotion Regulation Q-Scale; Shields & Cicchetti, 1997). Study design/analysis was preregistered (<https://osf.io/pgzvh>). DSEM was conducted using Mplus (Mplus v.8.11; Muthén & Muthén; 1998-2017), using Bayesian Markov chain Monte Carlo with a Gibbs sampler. We examined 3 interpersonal modality-pairings of Mface-Iface, Mgaze-Igaze, MTch-IvocA, and one infant intrapersonal modality-pairing, IVocA-Iface. Each 4-month modality-pairing was evaluated in a separate model in relation to 4-year outcomes; mother (maternal anxiety, maternal depression) and child (child emotion dysregulation, child internalizing-problems) outcomes were modeled separately, adjusting for covariates (delivery method, 6-week income, 6-week maternal education, 4-month maternal anxiety/depression). DSEM evaluates three kinds of predictability processes: (a) intrapersonal contingency (autoregression); (b) interpersonal contingency (cross-lagged relations); and (c) intra-individual residual variance, or “volatility.” Higher volatility (less predictability) reflects greater ebb and flow around the mean; lower volatility (more predictability) indicates staying closer to one’s mean level.

Results

Results offered limited support for our hypotheses. (a) Higher maternal facial-affect autoregression (greater facial stability) predicted higher 4-year child internalizing problems; (b) higher 4-month infant facial-affect volatility predicted lower 4-year child internalizing problems. Only child internalizing was significant as an outcome, consistent with Somers et al. (2025). Four-month maternal anxiety and depression predicted 4-year mother anxiety and depression, regardless of 4-month contingency processes.



Discussion

Greater 4-month maternal facial stabilization (like a momentary “still-face”) may be a risk factor in development. It predicts higher 4-year child internalizing problems as well as infant disorganized attachment (Beebe et al., 2010).

Greater 4-month infant facial-affect volatility, a greater use of the range of positive and negative affect, e.g. a highly affectively communicative infant, may be developmentally adaptive, predicting fewer 4-year internalizing problems.

Significant maternal depression and anxiety were stable from 4 months to 4 years, over and above 4-month contingency processes.

Four-month higher maternal facial stability, and lower infant facial volatility, set a developmental trajectory toward higher child 4-year internalizing problems, over and above 4-month maternal depression/anxiety. Thus, child internalizing problems are likely a characteristic of the dyad. Nevertheless, findings are exploratory and are interpreted with caution due to low power for DSEM.

Abstract 2 Title: Longer Timescales Reveal Contextual Differences in Infant–Mother RSA Coherence

Respiratory sinus arrhythmia (RSA), an index of parasympathetic regulation of cardiac activity, is increasingly used to examine physiological synchrony in parent-child interactions. RSA synchrony has been proposed as a biomarker of co-regulation, reflecting how caregivers and infants jointly adjust their physiological states. However, studies of mother-infant RSA synchrony have primarily relied on static, episode-level metrics, overlooking evidence that physiological coupling fluctuates and can shift in sign (positive vs. negative) and leader-follower dynamics (infant- vs. mother-leading; Mayo & Gordon, 2020). These constraints limit our understanding of how dyads coordinate physiological states dynamically across changing environmental demands.

Advances in continuous RSA estimation now allow time-resolved synchrony analysis (Abney et al., 2021), but challenges remain. Appropriate analytic tools must address two core challenges: (1) physiological signals are inherently nonstationary, and (2) synchrony may occur at multiple timescales. Wavelet coherence addresses both by decomposing signals into time-frequency space and quantifying coupling as it unfolds over time. Although increasingly used in neuroscience, applications in developmental physiology have primarily emphasized coherence magnitude, which indexes coupling strength but not whether synchrony is positive or negative, or whether one partner's changes precede the other's. Leader-follower dynamics and the direction of synchrony may shift with social context and have been linked to behavioral regulation (Rousseau et al., 2020; Suurland et al., 2022), motivating the need to incorporate these features into synchrony research. Phase angle information derived from wavelet coherence allows examination of these dynamics. The present study used phase angle metrics to characterize the direction and leader-follower dynamics of RSA synchrony in 90 mothers and their 4–6-month-old infants during the Still Face Paradigm. We quantified the proportion of time that dyads spent in mother-leading, infant-leading, positive, and negative synchrony across initial play, still-face, and reunion. These estimates were computed across four frequency bands that capture meaningful variation in RSA signals and



temporal scale of dyadic interaction, from frequencies near the rate of respiration (0.2-0.33 Hz or 3-5s) and halving down to 0.03-0.032 Hz (31-33s), which represents the lowest frequencies resolvable within the two-minute segments of each phase. Multiple timescales were examined exploratorily to test whether synchrony dynamics differ between rapid autonomic responses and slower, interaction-level regulation.

Results revealed context-specific shifts in synchrony direction and leader-follower dynamics. At the 31-33 second timescale, dyads spent a significantly greater proportion of time in mother-leading synchrony during the reunion phase ($M = 0.56$, $SE = 0.028$) compared to initial play ($M = 0.45$, $SE = 0.027$, $p = .02$). At the same timescale, negative synchrony was significantly more prevalent during initial play ($M = 0.29$, $SE = 0.022$, $p = .001$) and still-face ($p < .001$, $M = 0.30$, $SE = 0.022$) compared to reunion ($M = 0.18$, $SE = 0.022$). These findings suggest that longer-timescale regulatory coupling may differentiate typical social engagement from recovery from social perturbations. This approach demonstrates that leader-follower dynamics and direction of synchrony change by interaction context and timescale. Moving beyond magnitude-only coherence improves characterization of dyadic co-regulation and may offer novel markers of adaptive vs. dysregulated stress responses.

Abstract 3 Title: From salience to semantics: multilevel hierarchical contingencies organise parent-infant joint attention

Despite extensive evidence that infants learn more effectively in face-to-face social contexts than from passive screen exposure, we still lack detailed understanding of the real-time, adaptive mechanisms through which caregivers tailor their communicative behaviour to infants' attention. In this study, we investigate how parental social signals during early interactions are structured across multiple hierarchical levels—from low-level sensory salience to higher-order informational and semantic features—and how these features dynamically couple with infants' moment-by-moment attention during play.

To address this, we collected semi-naturalistic table-top joint play data from 67 mother-infant dyads (33 at ~5 months; 34 at ~15 months). Interactions were filmed at 50 fps with three synchronized cameras capturing infants' gaze behaviour, and the caregiver. Infant gaze to objects and to the mother's face was manually coded frame-by-frame.

Maternal behaviour was quantified using a multimodal feature-extraction pipeline integrating automated computer vision and computational linguistics. For the auditory domain, we used automatic transcription (WhisperX) to time-align maternal speech and to separate vocalisations from non-speech, and we computed spectral flux as a continuous measure of low-level acoustic salience.

Using computer vision (mmpose), we extracted maternal facial and hand movements from video via pose and landmark tracking, and we computed facial expression novelty to capture moment-by-moment changes in expressive content.

At the linguistic level, transcribed utterances were analysed to derive higher-order language features, including speech information rate, semantic surprisal, and toy naming events, allowing us to quantify both the informational density and semantic structure of maternal speech as it



unfolds during interaction.

To examine the temporal dynamics of interaction, we performed time-series and cross-correlation analyses linking infants' gaze data with the continuous streams of maternal features across multiple lags. These analyses allowed us to quantify not just static associations, but how changes in maternal speech and acoustic structure precede or follow infants' attentional engagement. We used cluster-based permutations to assess significance against chance level.

Our results reveal fine-grained, bidirectional contingencies: for instance, decreases in acoustic salience and facial and hand movement, co-occurred with increases in infant attention to objects, suggesting that mothers reduce potentially distracting auditory fluctuations when infants are engaged. Higher-level language features—particularly increases in object naming and speech information rate—were positively associated with subsequent sustained infant attention to objects. Notably, semantic surprisal did not show clear links with attention at either age, suggesting that infants in this age range may be more responsive to the amount and structure of information rather than to semantic predictability per se.

These findings demonstrate that early face-to-face interactions are characterized by multilevel, dynamic adaptation of caregiver behaviour in relation to infant attention, and underscore the value of multimodal, finely timed coding combined with information-theoretic measures to uncover the mechanisms by which social interaction scaffolds early learning.

Abstract 4 Title: Infant Real Time Coordination of Gazing and Smiling in Changes over Development and Varies by Partner

Infant social communication is organized in time. However, little is known about how infant multimodal behavior is coordinated in real time, how this coordination develops in the first year of life, and the role of the infant's interaction partner in this coordination. Here, we go beyond previous event-based conceptualization of early infant communication to ask how infant action in one behavioral modality dynamically influences infant action in another modality. We accomplish this with an innovative methodological approach: applying multilevel time-to-event (survival) analyses via multilevel Poisson regressions within a Bayesian multi-model inference framework. We examined the development of infant gaze and smile coordination longitudinally at 4 and 8 months in a sample of 58 families. Infants were observed during 2-minute home-based face-to-face interactions with mothers, fathers, and strangers. Behaviors were coded every second to characterize infants' gaze direction (at or away from partner's face) and infant smiles (present/absent).

To assess how infants coordinated behavior across modalities and how that coordination depended on infant and partner characteristics, we computed transitions among joint combinations of gaze state and smile state and submitted those transitions to multilevel Poisson regressions within a Bayesian multi-model inference framework.

Infant smiling transitions showed higher dependence on gaze state than the reverse. The probability of an infant transitioning from no smile to smile – smile initiation – was higher when the infant was gazing at the partner's face than when they were gazing away, while the probability of transition from smile to no smile – smile termination – was higher when looking away from partner's



face than when gazing toward. This pattern varied by infant age. The dependence of smile initiation on gaze state declined from 4 to 8 months. For example, the probability of smile initiation in the absence of gazing at the partner's face was higher at 8 than 4 months.

The probability of a transition to gazing at the partner's face was higher than the probability of gazing away at 4 but not at 8 months. The dependence of gaze on smile presence was stronger at 4 than 8 months. Specifically, the probability of gaze away from parent while smiling increased from 4 to 8 months. Differences were most accentuated when infants interacted with mothers, and least accentuated when interacting with fathers and strangers.

Findings provide new insights into infants' organization of social behavior across behavioral modalities. Specifically, gazing at the partner's face appears to be a behavioral stage on which smiling occurs. But over developmental time, infants become more capable of smiling in the absence of gazing at the parent. Likewise, they become more capable of gazing away while smiling. Early development may thus involve some degree of decoupling of gaze and smiling behavioral modalities. This decoupling was particularly evident in interactions with the father and stranger suggesting that infants may explore different coordination regimes with different partners over the first year of life. Further application of our analytical approach could yield insights into the temporal coordination of adult interactive behaviors.

Symposium 4.3 - What do we know about the bilingual brain? Novel insights from neuroimaging techniques in the study of early bilingualism

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Summary

Bilingual infants' early experience with complex linguistic environments has been proposed to impact language processing at the neural level. Now, advances in infant neuroimaging allow for testing this proposal by observing language processing in real time. This symposium aims to highlight recent findings about the bilingual brain during early language development, based on a range of neuroimaging techniques. We examine: (1) how prenatal and early postnatal experiences shape neural encoding of speech in Catalan–Spanish bilinguals, assessed using the Frequency-Following Response, (2) whether specialization for native languages is reflected in cortical tracking in Spanish–Basque infants, measured via EEG, and (3) the neural correlates of fast mapping in Spanish–English toddlers using fNIRS. Together, these studies provide important insights into how multiple language experiences guide the path to language acquisition.

Details

Abstract 1, Title: The effects of prenatal and early postnatal linguistic and musical environment on the neural encoding of speech sounds.

Infants show a native talent for language acquisition since the very early stages of development. Behavioral evidence has shown similar developmental trajectories in the acquisition of the mother tongue regardless culture and language, evolving from babbling during the first half year to first



word utterances by the age of 10-18 months. Starting from the tuning to the phonetic repertoire of the mother tongue, language acquisition entails a sophisticated fine-grained neural machinery across the entire auditory system to capture the complex spectro-temporal acoustic features that characterize the speech sounds. And yet, the fine tuning of all these mechanisms is dependent on the interaction between the infant and its environment, an interaction that starts even before birth, during the fetal life. Here, I will report on three studies that demonstrate the profound impact of prenatal and early postnatal auditory environment, both linguistic and musical, on the mechanisms supporting the neural encoding of the speech signal.

The present work capitalizes on a specific brain response recorded with the EEG to speech sounds: the Frequency-Following Response (FFR). The FFR captures with great fidelity the neural tracking of the speech signal features, such as its fundamental frequency (F0) and its formants (particularly F1) across the entire auditory hierarchy. FFRs were elicited to the speech stimulus /oa/ (250 ms long, delivered in alternating polarities at 65 dB SPL to the right ear at 3.39 Hz; F0=113 Hz; F1 /o/=452 Hz; F1 /a/=678 Hz) and recorded in neonates (and 6 months and 1 year old infants in study 3) through one electrode attached at the forehead (Fz) and reference at the right mastoid (bandpass filter 30-1500 Hz). Spectral analysis (FFT) was used to quantify the neural encoding of F0 and F1 on averaged and subtracted responses to alternate polarities, respectively. In the first study, focusing on prenatal music exposure, mothers were interviewed on her music listening habits (through loudspeakers) during the last 3 months of pregnancy, and neonates classified as daily exposed or less-often exposed. In study 2, mothers were asked whether they used more than one language during the last 3 months of pregnancy. In study 3, the LEAT questionnaire was used to quantify the total number of months of bilingual exposure during the first year of development.

Across the three studies reported here, the neural encoding of the F0 was affected by the auditory environment: prenatal music exposure enhanced F0 amplitude; prenatal bilingual exposure attenuated F0 amplitude, whereas postnatal bilingual -compared to monolingual- exposure had a bimodal effect, attenuating F0 amplitude at 6 months but enhancing it at one year of age. F1 neural encoding was also affected by bilingualism, with a negative effect during early (prenatal) exposure but with an enduring positive effect during the first year of development. The results of the three studies clearly demonstrate the positive impact of the acoustic environment, both linguistic and musical, during early language acquisition. Together, they pave the way both for intervention measures in cases of suspected delay and dedicated policies to boost language acquisition.

Abstract 2, Title: Cortical tracking of native and non-native speech by monolingual and bilingual infants during the first year of life.

Monolingually-exposed infants can differentiate their native language from a non-native language belonging to a different rhythmic class at birth and from a language of the same rhythm class several months later. Bilingually-exposed infants appear to follow a similar developmental trajectory, and to also differentially process their two native languages already in the first months of life, even when they belong to the same rhythmic class. These abilities have been attributed to infants' progressive attunement to the prosodic properties of the speech signal as a result of pre- and post-natal exposure to their native language or languages.



Recently, cortical tracking of speech (CTS)—the synchronization between neural oscillations and the temporal structure of the speech envelope—has been proposed as a neural mechanism underpinning the ability to process and encode speech information at different timescales. There is emerging evidence that monolingual infants differentially track native and non-native speech already in their first months of life, but to date, CTS has not been assessed in bilingual infants. Here, we tested whether between- and within-language discrimination is reflected in different CTS patterns and whether these are influenced by early bilingual experience. For this purpose, we measured CTS in monolingual and bilingual infants across development (4 and 7 months), at slow frequency rates (<3 Hz, Delta band, corresponding to the phrasal rate in speech; and 4–8 Hz, Theta band, corresponding to the syllable rate).

CTS data from 81 infants (47 monolingual; 34 bilingual, with L1 exposure $M = 60\%$) were analyzed. Infants were recruited from a large-scale longitudinal study of language development in monolingually and bilingually raised children acquiring Spanish and/or Basque from 4 months to 7 years. We assessed CTS at 4 and 7 months to test the prediction that CTS efficiency reflects gradual differences in processing between and within rhythmic-class languages. We recorded continuous electroencephalography while infants listened to ~5-minute stories in Spanish and Basque (native/dominant languages, same rhythmic class) and English (non-native language, different rhythmic class).

We analyzed CTS using the mTRF model (a computational approach assessing correlations between stimulus features and EEG data) in the Delta and Theta bands. mTRF results for between-rhythmic-class processing (English vs. native/dominant language) showed higher Delta and Theta values for the non-native compared to the native/dominant language. Bilingualism and age effects were not significant. We then analyzed within-language discrimination separately for monolinguals and bilinguals. Monolinguals showed differential tracking between the native and the familiar (non-native but present in the community) languages: the familiar language showed higher mTRF values, behaving similarly to English. In bilinguals, however, no significant differences emerged, indicating similar tracking of both languages to which they are directly exposed.

These findings confirm that infants differentially process native and non-native languages, and that exposure patterns can influence the processing of same-rhythmic-class languages. We will discuss the CTS results to native and non-native language(s) in relation to individual exposure patterns.

Abstract 3, Title: Fast Mapping Across Languages: Neural Signatures of Word Learning in English-Spanish Bilingual Toddlers

Early word learning is a hallmark of language acquisition, yet the neural mechanisms supporting bilingual children's acquisition of new words remain poorly understood. Prior neuroimaging work with adult second-language learners shows left-lateralized frontal and temporal engagement during successful word learning and more bilateral recruitment when learning fails (Yang et al., 2015, *J. Neurolinguistics*). The present study investigates whether similar neural patterns emerge in early childhood by examining bilingual toddlers' acquisition of new words in each of their languages.



One way to capture word learning in young children is through Fast Mapping tasks, which provide a sensitive measure of children's ability to form word-referent links after minimal exposure. To our knowledge, this is the first study to examine the neural correlates of fast mapping in bilingual toddlers while directly comparing across each of the child's languages, offering a rare opportunity to assess whether bilingual toddlers engage shared or language-specific learning mechanisms across languages.

Method. English-Spanish bilingual toddlers (N=25; 24-36 months; Spanish-dominant) completed a Fast Mapping task consisting of two randomized language blocks (English, Spanish). In each block, children viewed familiar and unfamiliar objects. During Familiar trials, the known object was labeled ("look at the car!"), and during Unfamiliar trials, the unfamiliar object was labeled with a novel word ("look at the dax!"). A subsequent Retention block assessed whether children maintained the novel word-referent mappings in both languages. Eye-tracking measured recognition post-labeling, and functional near-infrared spectroscopy (fNIRS) recorded frontal cortex activation throughout the task. We assessed children's language dominance using parent questionnaires and vocabulary reports.

Preliminary results. Children engaged bilateral frontal regions while reliably mapping familiar word-referent pairs in both languages. In Spanish, children showed successful mapping of novel word-referent pairs and retention of these pairings; such behavior was accompanied by left-frontal activation—consistent with successful word learning. In contrast, children showed weaker mapping of novel word-referent pairs and retention of these pairings; such behavior was accompanied by broad activation across both hemispheres.

The dissociation between children's stronger learning in their dominant language (Spanish) and increased right-lateralized activation during English trials suggests that bilingual toddlers may recruit additional neural resources to support word learning in their non-dominant language. This study may ultimately provide one of the earliest demonstrations that language dominance modulates neural recruitment during early word learning, revealing how toddlers dynamically allocate neural resources across languages. These findings underscore the importance of assessing both languages in bilingual research and will ultimately advance our understanding on the mechanisms supporting bilingual children's early word learning.

Symposium 4.4 - New insights into infants' everyday social-emotional inputs drawn from naturalistic recordings of real-world interactions

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Summary

Although structured tasks have revealed key mechanisms of development, they cannot capture children's lived experience. We propose that expansive time, space, and caregiver responsibilities



at home shape children's everyday social-emotional inputs, with implications for what and how they learn.

Each of our talks leverage unscripted recordings of everyday interaction to document infants' real-world social-emotional exposures, from proximity to facial and spoken affect. Together, our findings offer complementary insights into the nature of infants' social-emotional input and how it changes over longitudinal time (Talks 1&2), as well as links between everyday emotional exposures and individual differences in child and caregiver functioning (Talks 3&4). Overall, infants' everyday social-emotional inputs are more variable and context-dependent than in structured interactions, underscoring the need to ground theories of social-emotional development in real-world input.

Details

Abstract 1, The Social Ecology of Early Language: How Family Proximity Scaffolds

Communication in the First 1,000 Days: Prior research links child-directed speech (CDS) to language growth, particularly during one-on-one, close-proximity interactions with caregivers (Ramírez-Esparza et al., 2014; Suarez-Rivera et al., 2023). Yet such work often isolates the dyad and averages across children, flattening the distinct environments from which communication actually emerges. How does CDS occur amidst the full complexity of everyday family life—with siblings, caregivers, and their shifting proximities? We examined the unique social ecologies that characterize individual families and shape children's pathways to language, investigating how features of natural family life—particularly proximity dynamics between the child and household members—shape the use of CDS across developmental time.

We used the First 1,000 Days video dataset, which captured 12 hours/day across infants' first 3 years. We analyzed 2,724 30-second clips of family social interaction from 11 children at 6, 12, 18, 24, and 30 months, sampled to reflect each child's natural distribution of social contexts (e.g., caregiver only, sibling present, whole family). We applied a computer vision pipeline (person segmentation and monocular depth estimation) to construct continuous proximity networks measuring the distance and spatial distribution of family members relative to the child. Trained coders annotated child vocalizations and CDS from any family member.

Descriptive analyses revealed substantial variability in caregiver proximity across development (Figure 1). On average, caregiver-child touch decreased from ~35% at 6 months to <10% by 30 months, while visible-but-distant time increased from ~20% to ~35%, reflecting the transition from physical co-regulation to emerging autonomy. Families varied markedly in caregiver availability. Some children experienced consistent supervision, whereas others were outside caregiver view in solitary or sibling-only contexts for up to 40% of sampled time in infancy.

Generalized linear mixed models revealed asymmetries in how the social environment shaped communication. CDS was significantly more likely in clear dyadic structures: close proximity to the child ($\beta = -1.10$, $p < .001$), fewer people ($\beta = -0.33$, $p < .001$), and spatial distributions where one family member was particularly close ($\beta = -0.27$, $p < .001$). Child vocalizations showed a weaker association with proximity ($\beta = -0.16$, $p < .001$), but were no longer significant when CDS was included in the model—suggesting proximity influences child vocalization primarily by facilitating



CDS.

Across all families, CDS and child vocalizations robustly co-occurred ($\beta=1.48$, $p<.001$). This coupling held across distances, and child vocalizations were more than twice as likely with CDS present, whether touching or meters away (Table 1). Coupling increased significantly during months with vocabulary spurts ($\beta=0.36$, $p < .001$), suggesting families adapt their communicative behavior during periods of linguistic growth.

While proximity affords the opportunity for CDS, children also actively shape this landscape. CDS becomes less likely at a distance, yet its co-occurrence with child vocalizations remains robust. This coupling intensifies during vocabulary spurts, suggesting a shift in how communication is scaffolded across development: as children move through their social worlds with greater independence, connection is increasingly maintained through vocal coordination. Future work will examine how other factors, like technology or affective climate, similarly modulate communicative coupling.

Abstract 2, How do infants learn about emotions? An investigation of natural facial and language input: Emotion understanding—or the set of abilities related to determining the emotions of others—is crucial for the development of healthy social interactions. But how do infants learn about emotions? What kinds of input do infants use to make sense of the emotional world? While entire research programs have been devoted to studying the mechanisms required for emotion understanding in infants, to date, we know very little about the emotional input infants receive in the real world.

Here, we use an existing naturalistic dataset to characterize the input for the early development of emotion understanding in infancy. Data were coded from the SEEDLings—the Study of Environmental Effects on Developing Linguistic Skills—corpus. SEEDLings is an existing comprehensive, freely available, and longitudinal corpus of one-hour video recordings of 44 infants in their homes once a month from 6 to 17 months of age (Bergelson, 2016). In the videos, infants were wearing a head-mounted camera so that their field of view was visible. Here, we used the dataset to describe infants' exposure to emotion information. First, we documented how often infants see faces, and then coded those faces for emotional expressions. We then transcribed the videos to identify the emotion language most often used by caregivers. Audio data were transcribed and run through LIWC software to extract language metrics.

Infants were generally exposed to far more partial than full faces, and that exposure to full faces, while low, increased over the time periods observed. Exposure to facial configurations hypothesized to serve as expressive prototypes for categories of emotion (e.g., happiness, anger) was extremely rare and decreased as a function of age (see Figure 1). When hypothesized expressive prototypes did occur, it was often in unexpected contexts, suggesting that they did not necessarily serve as a cue to the presumed emotional meaning. Lastly, unsupervised clustering of the facial movement data revealed emergent facial configurations that did not always or exactly map onto hypothesized expressive prototypes.



For exposure to emotion language, infants were generally exposed to very little. Across all participants and timepoints, the average percentage of emotion language used was 1.71%. Across the hour-long videos, parents produced between 1—321 positive emotion words ($M=56.84$, $SD=53.10$) and 0—109 negative emotion words ($M=15.04$, $SD=17.28$). Parents' use of positive emotion words showed a modest but non-significant increase over time whereas use of negative emotion words decreased significantly between the 6 and 12 months. Preliminary analyses found that higher negative emotion word use by parents was associated with more negative emotional facial configurations presented in view of infants. In contrast, there was no association between the amount of positive emotion words used by parents and positive emotional facial configurations. Continued analyses will investigate the correspondence between language and facial configuration information on a more momentary basis.

These results extend evidence that emotions are expressed heterogeneously in daily life, such that infants must learn much more than simple one-to-one mappings between facial configurations and context/behavior to acquire expressive vocabularies for emotion.

Abstract 3, Infants' Everyday Emotional Exposures are Shaped by Activity Context and Maternal Mental Health

: Children's everyday exposure to affective language is a key input for learning to identify, interpret, and regulate emotion (Bell et al., 2024), yet little is known about the everyday contexts in which such language occurs. Emotional speech is embedded in family routines, including mealtimes, bathtimes, play, and these contexts likely offer different opportunities to encounter positive or negative affect. Because children learn from the distribution and quality of these inputs, describing when and how much affective language children hear is critical for understanding early emotion development.

Parents' emotional functioning also shapes children's affective input. Although parent-child interaction is an established pathway for transmitting mental health risk (Gotlieb et al., 2020), research has focused more on parents' observable behaviors than language use. This is surprising given that emotion words predict children's emotion vocabulary (Nencheva et al., 2023), and adults with anxiety and depression show reliable differences in emotional language (Tackman et al., 2019). Yet it remains unclear whether such differences alter the affective input children receive.

Here, we first describe children's real-world exposure to affective language across everyday contexts and then test whether mothers with higher depressive or anxiety symptoms provide different affective speech environments. We consider emotional language as both a developmental input and a potential mechanism of intergenerational mental health transmission.

Data were drawn from the WCWH study and include 24-h LENA audio recordings and maternal depression/anxiety symptoms (MASQ). All families with children aged 0–3 years who contributed audio and mental health questionnaires were included ($N=53$; child age $M=1.99$ years, $SD=.76$).



WhisperX was used to generate full transcripts for daytime hours (7am–7pm). Positive and negative emotion words were extracted using LIWC-2022. A HIPAA-secure version of ChatGPT annotated transcripts for activity (e.g., media, mealtime, play) and positive/negative tone in 5-minute segments. GPT-based affect annotation has demonstrated reliability in prior work (Rathje et. al, 2024); we are also validating in our sample (73% accuracy for n=3, coding ongoing).

Across recordings, on average 1.76% of words were emotion words (1.18% positive; 0.43% negative). Much more of the day was coded as having positive (37.5%) or negative tone (21.1%). Tone was most positive during play, and significantly more positive than negative during play, singing, and media use ($p < .05$). Tone was more negative during conflicts/prohibitions and routine caregiving (e.g., diaper changes, baths, preparing to leave; Fig1). Maternal mental health symptoms (total MASQ) predicted children's exposure to emotion words ($r = .43$, $p = .048$; Fig2), driven by maternal anxiety ($r = .52$, $p = .021$). Maternal depressive symptoms were not related to emotion words ($r = .35$, $p = .15$), and tone was unrelated to any symptoms ($p > .05$). Post-hoc exploratory analyses suggested that more anxious mothers did not engage in more prohibitions ($r = .25$, $p = .81$), which we tested as a potential mediator of increased emotion-word exposure.

Overall, children's emotional input is systematically related to everyday activity contexts and maternal mental health. Routine caregiving tasks and prohibitions—which occupy a meaningful portion of daily life—are markedly more negative than play, suggesting that traditional free-play paradigms capture only a subset of children's everyday emotional experiences.

Abstract 4, Everyday Language Input Across Infancy Predicts Attachment Security at 12 Months

: Although the early language environment is typically investigated for its role in shaping children's linguistic skills, growing evidence indicates that it is also associated with children's socioemotional outcomes. A key socioemotional milestone of early life is the development of attachment, which forms through everyday communicative exchanges with caregivers across infancy. The current study examined associations between infants' language environments across the first year of life and attachment security at 12 months.

Parent–child dyads from three cohorts ($N = 165$; 59% male; 88% White; 21% low income) contributed up to eight day-long LENA recordings at 1, 6, 12, 18, and/or 36 months. Dyads completed the Strange Situation Procedure at 12 months; 63% of infants were classified as secure, and the remaining infants were classified as insecure (avoidant, resistant, or disorganized). LENA metrics included adult word count per hour (AWC), adult–child conversational turn count per hour (CTC), and child vocalization count per hour (CVC). Linear mixed-effects models estimated trajectories of each LENA metric from 1 to 12 months. Individual-level intercepts and slopes were then entered into logistic regression models predicting 12-month attachment security (secure vs. insecure), with statistical significance evaluated via bootstrapped 95% confidence intervals.

Average AWC across infancy was significantly positively associated with secure attachment



(OR=1.03, 95% CI[1.01, 1.06], $p=.002$). For every additional 100 adult words per hour, infants had a 35% greater likelihood of being classified as secure. Average CTC was also associated with security (OR=1.07, 95% CI[1.01, 1.14], $p=.014$), although this association was no longer statistically significant when both AWC and CTC were entered simultaneously, suggesting that adult speech level accounted for the shared variance. Changes in AWC and CTC across infancy were not associated with attachment security. Neither levels nor changes in CVC were associated with security at 12 months. Follow-up analyses testing the association between AWC at each individual timepoint (1, 6, and 12 months) revealed similar effect sizes (ORs=1.01–1.02; see Figure 1), indicating consistency across early development.

To explore later developmental trajectories, preliminary analyses were conducted for children who contributed LENA data at 18 and 36 months ($n=98$). In a mixed-effects model, attachment security was not associated with levels or changes in AWC or CTC across toddlerhood. However, there was a trend-level interaction between attachment security and age on CVC change ($\beta=0.24$, 95% CI[-0.02, 0.89], $p=.082$), such that securely attached infants showed steeper increases in vocalizations ($\beta_{\text{secure}}=0.46$, 95% CI[0.32, 0.60], $p<.001$) than insecure infants ($\beta_{\text{insecure}}=0.22$, 95% CI[-0.02, 0.46], $p=.034$). Data collection and coding for these later timepoints are ongoing; results presented here should be considered preliminary.

Together, these findings suggest that infants exposed to richer everyday language environments—particularly greater adult speech—are more likely to form secure attachments by 12 months. In turn, secure attachment may support continued vocal development during toddlerhood. Future research is needed to determine whether caregiver language input serves as a mechanism promoting attachment security or functions as an indicator of broader relational quality.

Symposium 4.5 - Prenatal maternal distress shapes early brain function: evidence across infancy and early childhood

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Summary

Research within the developmental origins of health and disease framework posits that prenatal environments shape offspring neurodevelopment across the lifespan. Prenatal maternal mental health is linked to offspring brain–behavior outcomes, yet how distinct dimensions of maternal distress unfold developmentally, and whether their neural signatures persist, resolve, or shift, remains unclear. Interpretation is further complicated by pronounced non-linear changes in resting-state EEG from birth through early childhood. This symposium integrates findings from three studies examining associations between prenatal maternal mental health with offspring EEG relative power across infancy and early childhood. Using complementary approaches, these studies reveal both convergent and divergent neural patterns across development. Together, the findings underscore the importance of developmental timing and specificity of prenatal exposures for identifying sensitive windows for intervention.



Details

Abstract 1: Dysregulated maternal anxiety during pregnancy influences frontal cortex asymmetry in infants

According to the Developmental Origins of Health and Disease (DOHaD) framework, maternal experiences during pregnancy can influence offspring risk for developing chronic diseases, including psychiatric disorders. These long-term influences may begin with early changes in the brain. Maternal prenatal mental health is thought to impact offspring brain development, including alpha-band asymmetry between the left and right frontal cortex (frontal alpha asymmetry; FAA; Gustafsson et al., 2018). FAA in later infancy (>3 months) and childhood is associated with impaired emotion regulation and may reflect a key biomarker for psychopathology risk, but little is known about the implications of early infant FAA (Perone & Vaughan, 2024). Additionally, while exposure to prenatal maternal depression has been linked to infant FAA (Lusby et al., 2014), comparatively less is known about anxiety. Anxiety may be especially important to examine because it is tightly linked to physiological arousal systems that directly shape the intrauterine environment (Glover et. al., 2011). Inconsistency in vigilance and reactivity signals may be particularly salient for the development of fetal neural circuits involved in threat processing and early regulatory capacities (Van den Bergh et al., 2020).

Herein, we investigated the links between dysregulation in prenatal maternal anxiety and infant FAA in longitudinal data collected from 43 mother-infant dyads recruited through obstetric clinics. Anxiety was measured using the Perinatal Anxiety Screening Scale (PASS) and GAD-7 (General Anxiety Disorder-7), collected from mothers twice prenatally at 24–28 and 32–36 gestational weeks, and postnatally when their infant was 6–10 weeks old. To quantify anxiety dysregulation, we applied Shannon's entropy to each participants' response patterns and averaged the output across measures and prenatal visits (Glynn et. al., 2018). Postnatal anxiety entropy was similarly calculated and averaged across measures collected at the postnatal visit. Using resting state EEG collected in 6- to 10-week-old infants, FAA was calculated separately for low (5–6.99 Hz), middle (7–9.99 Hz), and high (10–12.99 Hz) alpha frequency bands by subtracting the logged left frontal power from the logged right frontal power. Analyses controlled for adjusted gestational age at assessment, infant sex, maternal age, and household income categories. All p-values were FDR corrected to account for testing across three alpha frequency ranges.

We found that increased prenatal anxiety entropy predicted greater relative left alpha power in infants (Low: $t(35)=-2.986$, $p\text{-FDR}=0.005$; Mid: $t(35)=-3.711$, $p\text{-FDR}=0.002$; High: $t(35)=-3.054$, $p\text{-FDR}=0.005$) (Fig 1). Sensitivity analyses yielded similar results when controlling for postnatal anxiety entropy (Low: $t(33)=-2.231$, $p\text{-FDR}=0.032$; Mid: $t(33)=-2.482$, $p\text{-FDR}=0.032$; High: $t(33)=-2.368$, $p=0.032$). Notably, the postnatal entropy term was not significant in any model.

Frontal alpha asymmetry has been shown to shift rightward as infancy progresses (Perone & Vaughan, 2024). Thus, the infants exposed to lower prenatal anxiety dysregulation appear to exhibit



more mature cortical patterns across the full range of alpha frequencies. These results align with the broader DOHaD framework, suggesting that greater inconsistency in prenatal maternal anxiety signals may disrupt the stability of the intrauterine environment in ways that shape emerging neural systems involved in regulation and threat processing.

Abstract 2: The association between prenatal depression symptoms and infant EEG power at 7 months

Around 25% of pregnant individuals experience depression symptoms during pregnancy. This high rate is concerning given the associations between prenatal depression and poor birth outcomes such as shorter gestation, lower birth weight as well as later problems in cognitive and emotional development in infancy. In the current study, we leveraged a prospective randomized control trial to test three questions: (1) Does interpersonal therapy and enhanced usual care reduce depression symptoms during pregnancy? (2) Are depression symptoms during pregnancy related to infant brain function measured via electroencephalography (EEG) power at 7 months? and (3) Does reducing depression promote infant brain function? Participants were randomized into interpersonal therapy (IPT) and enhanced usual care (EUC; integrated maternity support services including counseling session and written psychoeducation) in early pregnancy to receive support through the end of gestation.

Participants ($n = 91$, $M_{age} = 30.03$, $SD = 5.65$ years) self-identified as 2% Asian, 8% African American/Black, 31% Latinx, 13% Multiracial, and 46% non-Latinx White. Depression symptoms were measured with the Edinburgh Postnatal Depression Scale (EPDS) three times during pregnancy. At 7 months postpartum, participants were invited to the lab with their infants ($M_{age} = 7.35$, $SD = 0.40$ months, 52% female) for EEG assessment. Infants sat on their mother's lap during the EEG recording and watched an experimenter blowing bubbles for about 2 minutes. Whole brain relative EEG power in theta (4-7 Hz), alpha (6-9 Hz), and beta (13-20 Hz) bands were extracted. All analyses covaried for parity, infant age at EEG assessment, and infant sex. This project was pre-registered at OSF.

Depression symptoms decreased over pregnancy. The rate of depression reduction was greater for the IPT group than EUC group ($d = 0.40$; 95% CI, 0.06-0.74) suggesting a more effective treatment. At early pregnancy, higher depression symptoms were correlated with greater whole brain relative theta ($r = .37$, $p < .001$) and alpha ($r = .25$, $p = .02$), and lower whole brain relative beta ($r = -.37$, $p < .001$) activity. The change in depression symptoms across pregnancy was not related to infant EEG metrics ($ps > .05$).

The results show that psychotherapy can effectively reduce depression symptoms during pregnancy. They also suggest that depression symptoms in early pregnancy are associated with altered brain function at 7 months. These associations are in the expected direction signaling greater relative power in low frequency bands (theta and alpha) and lower relative power in high frequency bands (beta) with higher depression symptoms. This pattern of high power in low frequency bands and low power in high frequency bands is associated with altered neurodevelopment. By the time of the conference, we will present findings testing whether decrease in depression symptoms mediate the association between treatment (IPT vs. EUC) and infant EEG power.



Abstract 3: Associations between Prenatal Maternal Stress and Functional Brain Activity at Age 3

Mounting evidence suggests that prenatal maternal stress is associated with alterations in offspring neurodevelopment, particularly in infancy (Pierce et al., 2019, 2019; Troller-Renfree et al., 2020). However, the long-term persistence of these neural signatures remains poorly understood. Specifically, it is unknown how prenatal stress relates to brain function at 3 years of age. This developmental window is critical to investigate because recent evidence suggests that functional brain development is not linear across infancy and toddlerhood (Sandre et al., 2025; Wilkinson et al., 2024). Furthermore, other reports have indicated that associations between adversity (Jensen et al., 2021) and cognitive functioning (Nikolaeva et al., 2024) may manifest in opposite directions for higher-frequency bands during the preschool period, compared to the patterns typically observed in infancy. Consequently, it is unclear whether the neural deficits often seen shortly after birth persist, resolve, or present as inverted patterns of activity by age 3.

Participants are 51 mother-child dyads (anticipated N=100) drawn from ongoing data collection in a sociodemographically diverse cohort (32% Black; 41% Latino/a; 49% female). Maternal stress was assessed via the STRAIN, a semi-structured interview of the mother. Specifically, total counts of stress and adversity that mothers encountered during the prenatal period was used for the present analyses. Child brain activity was recorded using resting electroencephalography (EEG), focusing on relative power in the theta, alpha, beta, and gamma bands. A host of 10 covariates were examined, and only one significant covariate (maternal education) was retained to preserve power. Final analyses with a larger sample size will retain more covariates.

Preliminary analyses controlling for confounding maternal factors revealed that higher levels of prenatal maternal stress were marginally associated with higher whole-brain relative beta power ($\beta = .259$, $p = .061$), which reached significance in the frontal ($\beta = .279$, $p = .046$) and central ($\beta = .319$, $p = .019$) regions. In contrast, prenatal stress was not significantly associated with whole-brain EEG power in the theta ($\beta = -.165$, $p = .243$), alpha ($\beta = .141$, $p = .331$), or gamma bands ($\beta = .007$, $p = .960$). These findings suggest that the impact of prenatal stress on neural oscillatory patterns may evolve as children transition from infancy to the preschool years, as findings in the beta band are either in the opposite direction or were previously not observed (Pierce et al., 2019; Troller-Renfree et al., 2020, 2023, 2025), but track with recently observed trajectory differences (Sandre et al., 2025). Results will be discussed in a broader framework detailing the trajectory of stress-related brain development and the implications of non-linear functional maturation for early identification and intervention.

Symposium 5.1 - Lessons from AI for infant learning

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Summary

Recent AI models implement efficient learning algorithms and acquire rich internal representations. These are the very processes that characterize infants, who learn, adapt and build structured knowledge from limited data. This symposium asks how such models can illuminate infant learning. We focus on “developmental NeuroAI”: using artificial neural networks as testable theories of developmental change. The first talk presents a curiosity-driven active-inference robot that acquires compositional language-action mappings from sparse input. In the second talk, curiosity and scaffolding are used to train multi-task recurrent networks on compositional cognitive tasks, relating their emerging connectivity and dynamics to developing human brains. The third talk argues that human infants exploit an extended helpless period to learn foundational representations from rich sensory input. In a final discussion, implications for core theories of infant learning will be drawn.

Details

Abstract 1

Curiosity-Driven Development of Language and Action in Robots: Scalable Compositional Learning and Emergent Exception Handling

Human infants develop remarkable generalization abilities in language and action through limited experience, suggesting mechanisms beyond large-scale supervised learning. To explore these mechanisms computationally, we constructed a self-exploratory robot learning framework that integrates reinforcement learning with the active inference principle, allowing curiosity-driven developmental learning. The model extends our prior supervised approach (Vijayaragavan et al., 2025, Science Robotics) toward autonomous, intrinsically motivated exploration. This framework addresses the long-standing “poverty of the stimulus” problem by showing how rich generalization can emerge from sparse examples through self-generated experience.

We tested four primary hypotheses:

H1: Generalization is enhanced by compositional scale, such that larger combinations of verbs, adjectives, and nouns yield stronger generalization.

H2: Curiosity combined with motor entropy enhances developmental learning, accelerating both learning speed and coverage.

H3: Generalization follows rote learning, consistent with the “verb-island” hypothesis by Tomasello (2003).

H4: Primitive actions precede complex actions, as observed in infant motor development (Smith & Thelen, 2005).

In addition, we proposed a fifth exploratory hypothesis:

H5: Exception-handling rules can be learned through exploratory development, exhibiting U-shaped performance curves - a hallmark pattern in developmental psychology.

Experiments were performed in simulation with 10 independent robot agents, each modeled as a



mobile manipulator equipped with vision, tactile, proprioceptive, and auditory (command/feedback voice) modalities. Robots learned mappings between linguistic commands and sensorimotor actions through 60,000 developmental epochs.

Methods.

Each imperative sentence consisted of compositional combinations of verbs, adjectives, and nouns (e.g., push left blue pillar). Only one-third of all possible combinations were used for training, with the remainder reserved for testing generalization. The model's actor-critic architecture, implemented in a variational recurrent neural network (VRNN), minimized expected free energy with curiosity and motor entropy terms, promoting self-exploration of unpredictable sensory consequences.

For the new exception-handling experiment, two abnormal linguistic rules were introduced: when asked to "push forward red pole," the robot should instead perform "push left blue pillar," and vice versa. These exceptions constituted 2 of 180 total compositions.

The simulations confirmed all four original hypotheses. Robots trained under curiosity-driven learning achieved up to 90% success on unlearned compositional commands despite being trained on only 33% of the dataset - demonstrating that generalization strength grows nonlinearly with the scale of compositionality. Moreover, curiosity combined with motor entropy substantially improved developmental learning compared with curiosity-free baselines. Developmental trajectories showed that rote learning preceded generalization, and that simpler perceptual-motor actions such as watch and be near emerged earlier than complex manipulations like push or touch the top.

In the new exception-handling task, robots successfully learned the exceptional mappings through exploration, showing a U-shaped performance curve: initial success, decline during over-generalization, and eventual recovery after refinement. This dynamic mirrors classic patterns of over-regularization in child language acquisition.

Together, these findings demonstrate that curiosity-driven developmental learning within an active-inference framework enables not only scalable compositional generalization but also acquisition of exception rules - bridging computational modeling and developmental psychology.

Abstract 2

How Curiosity and Scaffolding Shape Infant Minds

Infants possess remarkable active learning and exploration skills that allow them to build complex systems of knowledge quickly and effectively. They also live in a social environment, where their caregivers continuously support their learning. However, the extent to which curiosity-driven exploration and environmental scaffolding shape infants' cognitive and neural architectures remains difficult to establish with behavioural and neuroimaging data alone. Here we adopt a computational approach to address this issue.

We take a state-of-the-art recurrent neural network (RNN) model and endow it with a curiosity-



driven learning mechanism inspired by infant studies, in which the learner preferentially samples tasks that maximise expected learning progress (e.g., Poli, Serino, Mars & Hunnius, 2020). In parallel, we implement a form of scaffolding in the sense of Vygotsky's zone of proximal development, by structuring the training curriculum from easier to harder tasks. Our central hypothesis is that curiosity and scaffolding jointly produce networks that (i) learn faster and generalise better across tasks, and (ii) develop internal architectures that are more brain-like in both topology and functional coding.

The study population consists of four RNN "learners" trained on the same battery of 100 compositional cognitive tasks, including variants of go, delayed go, anti, delayed anti, and one- and two-alternative decision-making. These tasks are constructed compositionally: e.g., "delay" and "anti" operations can be added to different base tasks, allowing us to track how shared computations are implemented neurally. The four models differ only in training regime: (1) Curious (intrinsic motivation only), (2) Scaffolding (ordered curriculum only), (3) Curious + Scaffolding, and (4) a Control trained with a flat task sampling distribution and no scaffolding.

We compare models along three dimensions. First, behaviourally, we assess learning speed, asymptotic performance, and generalisation to held-out task combinations. Second, at the level of network architecture, we analyse the weighted recurrent topology and topography of each trained model and compare these to empirical structural connectivity from the developing Human Connectome Project (dHCP, ~700 neonates), focusing on degree distributions, modularity, and spatial embedding. Third, at the level of neural dynamics, we quantify mixed selectivity, co-localisation of units tuned to related task factors, and parallelism of coding directions across contexts, leveraging the compositional structure of the task set (e.g., shared "delay" or "anti" components across nominally different tasks).

Preliminary results indicate that the Curious + Scaffolding model learns the full task set with fewer training steps, achieves higher accuracy on novel task compositions, and exhibits more modular and spatially organised recurrent connectivity than the Control. Moreover, its units show richer mixed selectivity and more parallel coding of shared sub-operations across tasks, bringing the representational geometry of the model closer to that observed in biological data. Together, these results suggest that curiosity-driven exploration, when combined with an appropriately scaffolded environment, can substantially shape both the functional and structural organisation of artificial neural networks in ways that may illuminate mechanisms of human cognitive development.

Abstract 3

Learning Foundational Representations in Early Infancy: Insights from Neuroimaging and Artificial Intelligence

Human infants spend an unusually long postnatal period in a state of helplessness. Rather than reflecting evolutionary compromise, this period may provide the ideal conditions for constructing a



foundation model of the world – a dense, flexible representational substrate derived from continuous sensory input and comparison-based learning. Recent theoretical work proposes that infants exploit their extensive early exposure to richly structured environments to build general-purpose representations that later enable rapid learning of words, actions, and concepts, much as modern AI systems benefit from broad pre-training before task-specific fine-tuning.

New large-scale awake infant fMRI data support this view. Even at two months of age, infants exhibit surprisingly mature representational geometry in ventral visual cortex, with robust distinctions among categories and emerging organisation by animacy and real-world object size. These neural patterns closely align with the representational structure of deep neural networks trained on naturalistic visual statistics, suggesting that infants' early perceptual systems may extract feature manifolds analogous to those learned in high-performing AI models. Crucially, these representations appear before infants show behavioural evidence of categorical organisation, and they do not arise in a simple bottom-up, hierarchical sequence.

Together, these findings suggest that early infancy may function as an intensive representational learning phase, in which neural systems adapt to the statistics of the sensory world to acquire broadly tuned, transferrable internal models. Such models could dramatically reduce the data demands of later learning, providing a principled explanation for infants' rapid vocabulary growth, accelerating conceptual development, and flexible generalisation.

This talk will argue that developmental neuroscience and machine learning are converging on a shared framework: foundation-model learning through rich, unlabelled input. By integrating infant neuroimaging results with computational insights from deep learning, we can begin to formulate explicit, testable theories of how the human brain constructs its earliest representations – and how this extended period of postnatal “helplessness” may be a uniquely powerful feature, rather than a developmental constraint.

Symposium 5.2 - The role of sleep in early learning, problem-solving and language

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Summary

Sleep, a daily and universal behavior, is key for development across multiple domains (Riggins et al., 2024), and its disruption can negatively impact these processes (Spruyt, 2019). This symposium takes an in-depth look at how variations in sleep shape developmental trajectories in memory, language, and motor skills, considering methodological, age-related, and cultural differences. Paper-1 introduces a multi-method approach to assess sleep and functional brain responses to language in Italian newborns within a hospital setting. Paper-2 uses home-based sleep monitoring to investigate problem-solving skills in preterm and term infants from the US and



Brazil. Paper-3 uses polysomnography to investigate how sleep supports memory longitudinally in North American toddlers. Together, these studies underscore how sleep drives early development, inviting discussion on how its emerging rhythms advance our understanding of neurocognitive and behavioral maturation in different contexts.

Details

Abstract 1: Non-Invasive Approaches to Newborn Sleep Monitoring in Cognitive Research

Introduction: Newborns spend most of their time asleep (Tarullo et al., 2011) and actively learn while sleeping (Sullivan et al., 1991; Fifer et al., 2010; Benavides-Varela et al., 2011; Gervain et al., 2008). Despite the predominance and developmental relevance of sleep, sleep-state monitoring remains difficult and is rarely integrated into studies of early cognition. One reason is newborns' unique sleep architecture - short bouts, highly variable durations, and frequent, ambiguous transitions between active and quiet sleep (Anders & Keener, 1985; Lamblin et al., 2013). Another challenge concerns the methodology. Traditional sleep classification relies on polysomnography, i.e., the gold-standard combining EEG, EOG, and EMG. EEG, the critical component for distinguishing sleep states, is rarely feasible in cognitive experimental settings with newborns. Therefore, more practical, non-invasive measures such as heartbeat patterns, respiration signals, and video-based observations are increasingly used. Determining which of these provides the most reliable window into newborn sleep is essential toward advancing sleep-sensitive research in early cognitive development. Another critical issue concerns the extent to which experimental stimulation may influence behavioral states, potentially affecting the reliability of these alternative measures. This study evaluates and compares non-invasive sleep-monitoring methods in newborns, examining both their agreement with EEG and their susceptibility to experimental manipulation.

Method: One-hundred eighteen healthy full-term newborns (2–5 days old) were assessed in a hospital setting during a 20-minute auditory verbal memory task, consisting of two five-minute auditory periods alternating with two five-minute silent periods (Benavides-Varela et al., 2011). Sleep state was simultaneously monitored through EEG (11 channels), breathing rate (respiratory band), video recording, while functional brain activity was recorded with high-density fNIRS. EEG characteristics of the two sleep states were scored by a sleep expert (Lamblin et al., 2013; n=32). Videos were coded following videosomnography criteria (Grigg-Damberger, 2017; n=86) and respiration was assessed via breath-to-breath variability across one-minute epochs (Isler et al., 2016; n=80). The percentage of agreement was calculated across all epochs used to quantify how well the combination of video and respiration measures matched the gold-standard EEG classification.

Results: The highest agreement occurred between video and EEG (78.3%; n=31), followed by respiration and EEG (74%; n=26). Agreement remained consistent across silent and auditory-stimulation periods: video–EEG (78.10% vs. 78.47%), and respiration–EEG (74.88% vs. 73.03%). Combining the epochs where respiration and video matched EEG, the agreement increased to 89%.



Discussion and Conclusion: This study investigated the feasibility of a multi-method approach for newborn sleep-state classification during functional recording. Our findings demonstrate that combining behavioural (video) and physiological (respiration) measures provides an accurate estimate of sleep state when compared with the gold-standard EEG. Agreement across measures remained stable during silent periods and during auditory stimulation, indicating that the presence of external sounds does not compromise the reliability of sleep-state classification. Overall, the findings support the use of a non-invasive multi-method approach to monitor sleep in developmental cognitive research.

Abstract 2: Napping Does Not Benefit Preterm Infants' Problem Solving as Well as It Does Full-Term Infants'

Infants born premature show less mature active sleep state organization than full term infants. Active sleep in infancy may facilitate learning via synapse formation and pruning, suggesting that premature infants may miss some learning and memory sleep-related opportunities. Moderate-to-late-term premature infants (MLPT) comprise 80% of infants born preterm. MLPT lack the high incidence of neurologic/medical problems common to very-extremely preterm infants, prompting assumptions that they “catch up” developmentally. However, MLPT can slip through the cracks and display later attentional and learning problems. It is unclear whether studies of the benefits of napping on cognitive functioning in full-term infants (FT) can generalize to MLPT. We compared MLPT as a model system of reduced capacity for focused attention, high quality sleep, and motor control to FT to ask whether napping with training improves problem solving in a compromised system.

45 FT infants (6-8 months old) and 32 MLPT infants (32-37 weeks gestation, 6-8 months corrected age) from the United States and Brazil participated to date. We chose this age range because sitting is emerging and infants are typically not yet crawling. An independent samples t-test revealed that FT slept ($M_{\text{sleep time}} = 10.19$ hrs) an hour more than MLPT ($M_{\text{sleep time}} = 9.19$ hrs) the night before the study.

We taxed infants' attentional resources with a sitting/reaching task designed to pit maintaining balance in independent sitting against inhibiting a prepotent reach to a target object. Infants reached for hidden toys five consecutive times through one of two openings set in an upright board (A) and then switched to the other opening (B). After 2 hours, infants repeated the task. Half of the infants in each group (FT, MLPT) napped during the delay and half stayed awake. Researchers coded from video multiple problem-solving and post-switch perseverative behaviors. Infants wore a head-mounted eye-tracker to document visual attention.

2 (FT, PT) x 2 (nap, no nap) x 2 (trial) x 2 (session) ANOVAs with gestation and nap condition as between-subjects factors and trial and session as within-subjects factors revealed significant main effects of trial, session, condition, and group, and a session x condition interaction on time to look to the target (Figure 1a); main effects of trial, condition, and group, a condition x group interaction, and a three-way interaction between session, condition, and group on time to reach (Figure 1b); and a trend towards a main effect of session and a significant session x group interaction on



balance control strategies (Figure 1c). Although not yet statistically significant, only full-term infants who napped perseverated less at the second session than at the first (Figure 1d).

Thus, MLPT infants found the task more physically and cognitively demanding than FT. MLPT infants who did not nap were significantly slower to solve the task. FT infants who did nap improved their ability to inhibit. These early differences for MLPT infants suggest that later attentional problems in school might be preceded by issues in infancy that may respond to intervention. Future analyses will look at individual differences in the relation between (in)efficient problem-solving and perseveration.

Abstract 3: Understanding longitudinal changes in sleep-dependent memory consolidation and underlying mechanisms

Introduction: Sleep supports memory consolidation in early childhood. Behaviorally, memories are better following an interval with sleep compared to an interval of wake. Memory consolidation can take place at the synaptic and systems levels. At the synaptic level, synaptic downscaling of some synapses while other parts of the engram go through synaptic upscaling improves memory. Both synaptic upscaling and downscaling are enhanced by sleep, particularly slow wave sleep (SWS). At the systems level, memories that are initially hippocampal-reliant are transferred (or copied) to the neocortex, where they are integrated with related memories. Memories are reactivated in hippocampal CA3 subfield, and these hippocampal ripples are coincident with sleep spindles and cortical slow oscillations. This coupled activity supports hippocampal-neocortical transfer and stabilization of memories in the cortex.

Hippocampal subfields essential to memory undergo protracted development leading to a hypothesis that hippocampal processing would be unable to support memory consolidation during sleep until after 18-24 months. As hippocampal CA3 develops slowly and CA1-CA3 ripple events (coincident with spindles and slow oscillations) are thought to underlie systems consolidation, sleep benefits observed before 18 months may instead reflect synaptic consolidation. To date, a similar sleep benefit has been observed in infants as in early childhood. However, prior studies have focused on a single age group with widely varying tasks. Thus, we are conducting a longitudinal assessment across this critical developmental period (16-31 months).

Hypotheses: We hypothesize that hippocampal-dependent memory consolidation is functional already at 16 months and thus expect that a consistent benefit of sleep will be observed from 16-31 months.

Study population: We have recruited 38 children (62.7% White/Non-Hispanic, 16.3% White/Hispanic, 4.6% Black/Non-Hispanic, 16.3% More than one race; 56% female) who were 16 or 21 months at enrollment and returned 5- and 10-months later.

Methods: At each timepoint, children performed an associative learning task followed by a 12-hr interval of overnight sleep and daytime wake (within subject, order counterbalanced) before memory was reassessed. Mid-density polysomnography was collected during the sleep interval.



Results: Memories were protected with overnight sleep similarly across all age groups ($F(3,86)=0.363$, $p=.780$). However, memories decayed less across the wake interval with age ($F(3,84)=3.930$, $p=.011$; Figure-1). This is consistent with our prediction of a similar sleep benefit across these age groups. Notably, consistent with our prior findings, forgetting over wake decreases with age. Next, we considered whether the mechanism may change across this period by examining the relation between SWS and the over-sleep change in memory. Available polysomnography and memory data so far is low, ranging from $n=6-14$. We found that SWS was not related to overnight change in memory at any age (all $ps>.32$). Likewise, the relationship between slow oscillation-spindle coupling and change in memory did not change with age (all $ps>.14$). Additional data may be necessary to assess the underlying mechanism.

Symposium 5.3 - A global perspective on socioeconomic and children's language development

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Summary

The pace of children's language development is often tied to socioeconomic factors, including parental education, household income, and closeness to urban centers. But most research is conducted in the U.S. and Europe, which represent a narrow range of possible socioeconomic conditions relative to the rest of the world. Moreover, recent studies taking place in Asia, Africa, and South America find more diverse, sometimes conflicting associations between socioeconomic factors, children's language exposure, and their learning outcomes. Because these children represent a large and rapidly growing portion of the world's youth population, understanding these associations is critical. This symposium presents four studies of children in fourteen countries across six continents collectively. These studies employ novel methods and draw from economically diverse communities within countries to capture causal pathways through which socioeconomic forces influence children's language development.

Details

Beyond SES: Caregiver Engagement Predicts Early Language in Socially Vulnerable Communities

Socioeconomic disparities in early language development are well documented in high-income, industrialised societies, where parental education and income strongly predict the quality and quantity of children's language input. However, far less is known about how socioeconomic factors relate to children's early environments and developmental outcomes in Majority World contexts, where caregiving practices and resource availability follow different cultural and structural patterns. This study investigates the relationships between parental education, the Family Care Indicators (FCI), and early language outcomes in infants and toddlers growing up in socially vulnerable areas of Buenos Aires, Argentina.



Hypotheses.

We hypothesised that higher parental education would be associated with higher FCI scores—reflecting more stimulating home environments—and that both parental education and FCI scores would be positively associated with children’s language outcomes.

Study population.

The sample included 180 infants and toddlers aged 4–24 months ($M = 13.94$, $SD = 4.29$; 96 males, 84 females) and their caregivers, recruited from Early Childhood Centres (Centros de Primera Infancia, CPI) located primarily in the southern districts of Buenos Aires. These areas exhibit the city’s highest rates of social vulnerability and infant mortality. Access to CPI is determined by the Social Vulnerability Index (SVI), which scores neighbourhoods on poverty, housing conditions, health, education, and access to services. Most caregivers were mothers (153), followed by fathers (20) and grandparents (6). Educational attainment reflected national patterns: 33.3% had not completed compulsory education, 71.7% had secondary education or below, and 12% had a university degree.

Methods. Caregivers completed the Family Care Indicators (FCI; UNICEF), which measure home stimulation across four domains: household books, household space, varieties of play materials, and play activities. Children’s developmental outcomes were assessed using the Bayley Scales of Infant and Toddler Development (Bayley-III), with language scores serving as the primary outcome. Pearson correlations assessed associations between FCI domains, parental education, age, and Bayley outcomes. Hierarchical linear regressions tested whether FCI scores predicted language outcomes above and beyond age, socioeconomic status (SES), and gender.

Results. Correlations showed that parental education was positively associated with several FCI domains, particularly books and play materials, but was unrelated to children’s language scores. Hierarchical regression indicated that caregiver play activities significantly improved the prediction of language outcomes above age and SES ($\Delta R^2 = .04$, $p = .006$). Adding gender, total FCI, or interaction terms did not account for additional variance, suggesting that neither SES nor gender uniquely shaped early language development in this sample.

Conclusion. In this context of social vulnerability, children’s language development was more strongly associated with what caregivers **do** with their children than with who they **are** in socioeconomic terms. Everyday interactive play—not parental education, gender, or overall material resources—emerged as the most meaningful predictor of early language skills. These findings highlight the importance of culturally grounded, strengths-based pathways to early learning in the Majority World and underscore the need to move beyond traditional SES-driven models when understanding and supporting children’s development.

Early Speech Input and Interaction in Rural China: Patterns and Predictors from Daylong Audio

This study provides one of the first large-scale looks at the daily language environments of young children in rural and peri-urban China. Using a previously employed speech-technology framework (Bergelson et al., 2023), we analyzed full-day LENA recordings from 283 children aged 12–36 months and applied the same standardized metrics used in global LENA datasets. This includes



child linguistic vocalization rates, which we call “child speech,” and adult vocalization count rates, known as “adult talk” (Bergelson et al., 2023). These automated measures, which are validated cross-linguistically and are linked to vocabulary growth and other gold-standard assessments, offer an insightful window into children’s daily communicative experiences.

What did we find? Across households, there was substantial heterogeneity in both the quantity and structure of early language input. Adult talk varied by nearly an order of magnitude. On average, adult talk levels were below those reported in high-income Western samples, but they fell squarely within the range of other low- and middle-income contexts. For the children themselves, we saw a strong and consistent developmental pattern: their speech-like vocalizations increased sharply from 12 to 36 months. This trajectory closely mirrors the age-related increases found in Bergelson et al. (2023), reinforcing that early vocal development is robust across diverse cultural and socioeconomic settings. Lastly, and consistent with global data, age emerged as the strongest predictor of child speech, reflecting the rapid maturation of infants’ and toddlers’ vocal capacities.

One of the most consistent findings replicated in our analysis is the positive association between adult talk and child speech. Children who heard more adult-produced speech also produced more of their own linguistic vocalizations, and this association strengthened with age. This pattern aligns closely with global results and underscores a key point: conversational accessibility (whether directed or overhead) shapes children’s early vocal behavior. Now, these correlations do not, on their own, establish causality; however, they *do* show that our China sample follows the broader global pattern linking children’s speech to the density of adult talk in their environment.

In contrast, traditional socioeconomic indicators, including parental education and household wealth, accounted for relatively little variation in either adult talk or child speech. This replicates one of the most striking conclusions of the global LENA study: that socioeconomic status, when measured through maternal education, is not a robust predictor of naturalistic speech input or output (Bergelson et al., 2023). In the Chinese context, however, the household caregiving structure played a much more meaningful role. For example, children living in a grandparent-only or migrant-parent household experienced significantly fewer conversational turns, while children with a stable, responsive primary caregiver showed richer turn-taking patterns. These results highlight the importance of caregiving arrangements, mobility, and multigenerational living, which are all factors especially salient in rural and peri-urban China and may shape interaction more strongly than formal SES.

Together, these findings both replicate *and* extend global findings. Applying similar analytic procedures to a culturally distinct population, this study demonstrates that several core patterns hold true beyond the original LENA studies (Ma et al., 2024; Bergelson et al., 2023), such as strong correlations of age and adult talk, weak SES effects, and high between-family variability. At the same time, the distinctive role of caregiving structure in China highlights context-specific mechanisms. These findings should inform the design of culturally grounded early childhood interventions and enrich global theories of early language development.



Investigating children's performance on object- and picture-based vocabulary assessments in global contexts: Evidence from Kisumu, Kenya and the San Francisco Bay Area, U.S.A.

Assessments of early linguistic abilities – such as the Peabody Picture Vocabulary Test (PPVT) – typically involve picture stimuli. As these language assessments spread worldwide, researchers make an implicit assumption: that children across contexts understand pictures in the same way, at the same developmental timepoint. What if this assumption does not hold for some or all kinds of pictures?

Three initial studies suggest that children living in environments without pictures succeed on object-based tasks, but underperform on picture-based tasks (Callaghan et al., 2011; Walker et al., 2013; Zhu et al., in press). Moreover, urban Western Kenyan toddlers who had looked at picture books more frequently were significantly more likely to learn a novel word for a picture than urban Western Kenyan toddlers who had looked at picture books less frequently, suggesting that variation in picture experience is related to variation in children's ability to learn from pictures (Zhu et al., 2025). Thus, picture-based assessments may underestimate some children's linguistic capacities.

However, all previous research was conducted with children prior to or at the very start of formal schooling. The present research investigates whether picture-based assessments might also underestimate the linguistic capacities of children with some formal schooling experience. Moreover, while cross-cultural work on children's picture comprehension contrasted object-based tasks with only one other kind of picture-based task (i.e., photographs, black-and-white line drawings), the present research contrasts objects with three common picture formats (i.e., photographs, clipart, black-and-white line drawings) to explore whether possible differences between object and picture stimuli hold across picture formats.

In Experiment 1, a preregistered sample of 128 3- to 7-year-olds ($M = 5.39$ years; range = 3.01 – 7.99, 92% attending daycare/school) from Kisumu, Kenya participated in a Swahili vocabulary assessment. Using a within-subjects design, each participant completed vocabulary trials in four formats (i.e., objects, photographs, cartoons, black-and-white line drawings). In Experiment 2, a preregistered sample of 64 3- and 4-year-olds ($M = 4.03$; range = 3.11 – 4.99, 100% attending daycare) from the San Francisco Bay Area, U.S.A. participated in the same vocabulary assessment in English.

For Experiment 1, a preregistered generalized linear mixed effects model showed that Kisumu children performed equally accurately across objects, photographs, and cartoons, but less accurately on black-and-white line drawings ($\beta = -0.44$, 95% CI $[-0.78, -0.10]$, $z = -2.55$, $p = .011$). However, exploratory analyses involving a Bayesian mixed effects model accounting for item-level effects showed no difference between objects and photographs (emmeans: -0.08 , 95% CI interval $[-0.67, 0.5]$), cartoons (emmeans: 0.02 , 95% CI $[-0.75, 0.75]$), or black-and-white line drawings (emmeans: 0.41 , 95% CI $[-0.25, 1.15]$), suggesting that a subset of line drawing items drove the accuracy difference. Preregistered analyses for Experiment 2 showed that San Francisco Bay Area children performed equally accurately across object, photograph, cartoon, and line drawing formats (all p 's $> .08$).



These findings suggest that caution is necessary in the use of picture stimuli. Acquiring knowledge about the cross-contextual development of picture comprehension will help researchers appropriately assess the linguistic abilities of children growing up in diverse global contexts.

Mapping the Global Geography of Childhood Conversation

Conversation is an essential component of language acquisition, yet little is known about the dynamics of children's conversations outside of Western countries, where research focuses heavily on their dyadic, one-on-one interactions with adults. It is often argued that children outside of these settings rarely converse directly with adults, spending more time in multiparty conversations (involving at least two other figures) or overhearing others' conversations. When these children do engage in dyadic conversation, it is more often with other children.

The size and consistency of these differences, as well as their underlying causes, are not well understood, and until recently, methodological limitations made it extremely difficult to test these claims in large-scale, cross-cultural studies. However, thanks to advances in speech processing technology, we can use software to automatically identify and quantify different kinds of conversation from naturalistic, day-long audio recordings taken in the homes of children around the world (Lavechin et al., 2020).

In this study, we analyze 23,000 hours of child-centered audio recordings taken from 840 children (mean age = 28 months; 404 girls) growing up in 11 countries (Fig. 1), representing urban, agricultural, and foraging groups across 5 continents (Gautheron et al., 2023). We quantify differences in the kinds and amount of conversations children experience in their daily lives. We then investigate how children's engagement in conversation is related to their age, gender, mother's education, and number of siblings.

We report three major findings. First, dyadic interactions with adults are *not* the most common type of conversation children experience overall (mean = 4.5min/hr). In 10 of the 13 societies, children most frequently experienced conversation in multiparty contexts (mean = 13 min/hr). In 5 societies, overheard conversation (mean = 5.4 min/hr) was more frequent than adult conversation; in another 4, there was no strong evidence for any difference (Fig. 2).

Second, dyadic child conversation is more frequent than dyadic adult conversation in Bolivia (Quechua and Tsimane) and Papua New Guinea (Yélî Dnye), consistent with prior reports in less urbanized non-Western societies. In addition, in the Solomon Islands, Mexico (Tzeltal), and Nepal, there is no difference in adult-child and child-child conversation (Fig. 2).

Third, children's exposure to conversation is greatly influenced by household size and education. Children with more siblings hear more multiparty and dyadic child conversation, but less dyadic adult conversation. Children whose mothers are relatively more educated engage in less conversation with other children, but not more dyadic adult conversation, as prior research would suggest. Finally, older children experience more multiparty and child conversation, but relatively less overheard conversation.



Taken together, our findings suggest that large parts of children's language learning may take place in much different contexts than are typically studied, most notably in multiparty contexts with many conversational partners, and with other children, particularly in smaller-scale societies. In addition, socioeconomic factors like maternal education may not predict greater adult-child conversation across cultural settings, contrary to research in Western countries. Our study represents the first steps in mapping out the global geography of conversation in childhood.

Symposium 5.4 - The organization and dynamics of the infant social brain

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Summary

Humans are profoundly social, and the adult brain contains specialized systems supporting social perception and evaluation. Yet how early these distinctions emerge, and how they change with accumulating experience, remains unclear. Infant neuroscience offers a unique opportunity to address these questions by revealing the organization of the social brain in the first year of life. This symposium brings together research from four laboratories across Denmark, Canada, and the United States, testing infants aged 3–12 months using diverse neuroimaging methods (fMRI, fNIRS, EEG/ERP), statistical approaches (trial-level mixed-effects & encoding models), developmental designs (cross-sectional & longitudinal), and social stimuli (faces/scenes, interactions/individuals, pro/antisocial agents, and re/irrelevant objects). Together, these studies highlight the value of infant neural methods for understanding the developmental origins of social perception and cognition and the foundations of human sociability.

Details

Abstract 1, Title: Understanding the development of neural systems supporting social cognition using infant fMRI

Abstract 1 text:

How does the neural architecture supporting social cognition develop in infancy? Behavioral studies suggest that some core aspects of human social cognition—the ability to reason about others' actions, mental states, and personality traits—develop within the first year of life. However, we have little understanding of how this ability is supported by neural systems in infants. Neuroimaging research in adults has found that social cognitive tasks elicit responses in a network of brain areas distributed across multiple anatomical zones, including medial prefrontal cortex (MPFC), medial parietal cortex (MPC), and the superior temporal sulcus (STS). This network, termed default network (DN)-B, is interposed with a distinct, parallel system DN-A that responds preferentially to tasks involving spatial content. Each network responds not just to cognitive tasks but also to visually perceived people and places, particularly when they are familiar to the participant. These results provide a path forward for studying social cognition systems in preverbal infants, by measuring the anatomical and functional development of DN-B.



Here we ask this question using fMRI in awake and sleeping infants. While technically challenging, infant fMRI offers substantial improvements over scalp recording methods like EEG and fNIRS typically used in infant brain research, providing the coverage and spatial resolution needed to measure brain-wide functional networks. To further increase spatial precision, we take the approach of studying neural responses within individual infants, scanned multiple times to provide sufficient statistical power. We present data from an ongoing project with $N = 11$ infants, each scanned 1 to 5 times between the ages of 3 to 9 months. While awake, infants were presented with dynamic, engaging videos of familiar and unfamiliar faces and scenes, in a 2x2 blocked design. Stimuli were tailored to each individual infant, including videos of caregiver faces and spatial environments from the home. While sleeping, we additionally collected high-resolution anatomical images and resting-state functional data when possible.

Our results demonstrate that infants as young as 3 months show responses to familiar faces within areas associated with DN-B, including MPFC, MPC, and STS. Like in adults, these areas respond more strongly to faces than scenes, and familiar than unfamiliar faces. Using resting-state data, we show that regions of DN-B within distinct anatomical zones are functionally connected, showing correlated activity in the resting state. Similar to adults, infants showed two distinct but neighboring networks that we refer to as DN-A and B. As age increased from 3 to 9 months, each network increased in size, but the overlap between DN-A and B decreased, suggesting a refinement in network topography. These results suggest that neural systems supporting social cognition are present, functionally responsive, and sensitive to social content and familiarity very early in development. They further suggest that the organization of these systems is refined during the first year of life.

Abstract 2, Title: Using fNIRS to study the neural basis of infants' perception of interactions between humans or artificial agents

Abstract Text 2:

Learning to recognize and interpret social interactions is a critical component of social cognitive development. A substantial body of behavioral research suggests infants begin to do this in the first year of life. Between 6 and 12 months, infants begin to show heightened attention to social interactions (e.g. Thiele et al., 2021), and infants use observed interactions as the basis for further expectations and social evaluations (Woo et al., 2022). Some of these studies use displays of humans in what are likely to be perceptually familiar arrangements (Thiele et al., 2021; Buon et al., 2014; Burns & Sommerville, 2014), while others use simplified displays of puppets or animated figures to depict schematic social interactions (Hamlin et al., 2007; Johnson et al., 2007; Powell et al., 2013). These studies raise questions about the neural substrates underlying infants' emerging understanding of social interactions: Does the infant brain already show functional organization specialized for processing interactions? If so, do specialized regions respond to social interactions regardless of format, or only to visually familiar human interactions?

In the current preregistered research, we addressed these questions by collecting fNIRS data while 7- to 9-month-old infants watched videos depicting two agents either interacting (one trying to help the other with a range of problems) or each acting independently. We refer to these as the "interaction" and "independent" conditions, respectively. Orthogonally, some videos consisted of recordings of human actors and others displayed animated characters (geometric shapes with eyes). Channels in the fNIRS array covered several regions of interest implicated in social interaction processing in adults (right and left posterior superior temporal sulcus [pSTS], medial prefrontal cortex [MPFC], and right anterior temporal lobe [ATL]), as well as a control region (right MT). Each trial was 20 seconds in length, and we compared activation during the final 10 seconds, as this was when the majority of the social interaction occurred in the interaction



condition. For each region of interest in each participant, we used some of the functional data to select one out of 3 or 4 possible channels as the functional channel of interest, and then used mean responses in left out data from those channels to conduct group-level tests (Powell et al., 2018).

Data collection is ongoing (current $N = 25$ of 40, 6m24d - 9m26d, 12 female). In the current sample, we observed higher activation to the interaction condition vs. the independent condition in only one region: MPFC ($t(24) = 3.328, p = .0014$). This activation pattern did not vary significantly by stimulus type (human vs. animated), and the difference was directionally larger for the animated stimuli. There was not a significant difference between conditions in the pSTS ($t(24) = 0.900, p = 0.19$), where selective responses to social interaction have been observed in adults (Isik et al., 2017), nor any evidence of an interaction with stimulus type. However, our analyses target the entire interaction period (seconds 10-20), which the agents spent acting together but not always oriented toward one another. In follow up analyses, we will investigate if this region responds even more selectively to images of two agents, or two humans specifically, oriented toward each other.

Abstract 3, Title: Infants assign value to the targets of others' attention

Abstract Text 3:

From early in life, infants learn more about objects when they are the targets of others' attention (Reid et al., 2004). Recent work suggests that young infants have a stronger version of this phenomenon: an altercentric bias (Southgate, 2020), where prioritized encoding of an event co-witnessed with someone impedes appropriate updating of that information (Manea et al., 2023). Infants in this study attended to an agent watching a ball being hidden in location A, then the agent left and the ball was transferred to B. Despite dividing their attention between ball and agent during the first hiding event, and fully attending to it during the the second transfer, infants misremembered the object at the location cued by the agent (A). This suggests that the cue is not a low-level driver of attention leading to better encoding, but a pointer to a relatively higher epistemic value event.

The current study aims to probe this idea of an internal epistemic value tracking based on others' attention by measuring theta-band activity in the EEG, a neural signature of readiness to learn, during the reveal of objects that infants could infer were previously the targets of others' attention. 8-month-old infants observed an agent gaze behind one of two occluders. The agent then disappeared and either the occluder covering the location attended by the agent (cued), or the other occluder (uncued), were lowered to reveal different abstract objects. Theta activity was measured during the object reveal. In the second part of the study, infants took part in a memory test in which we sought evidence that they better remembered the object that was revealed in the cued location. Each previously seen object (cued and uncued targets) were paired with shape-distorted variants (distractors) and relative looking time to target and distractor objects was measured.

31 infants contributed valid data to both the EEG and eye-tracking analysis. Infants exhibited greater theta band activity over occipital electrodes in response to seeing objects revealed in the cued location, than objects revealed in the uncued location. Importantly, greater theta was predictive of a familiarity preference for the cued object [$r(29) = .40, p = .025$], suggesting not only that infants assigned more value to the cued object, but that the degree to which they did so influenced their preference for this object when later revealed. Nevertheless, overall memory for



the object type (familiar, novel) was also influenced by condition with infants showing a novelty preference in the uncued object condition [$t(30)=2.48, p=.019$]. This suggests that although greater theta activity during encoding of the cued vs. uncued object predicted a familiarity preference, infants also encoded and remembered something about the uncued object. Considered together, these findings suggest that infants remember objects regardless of whether or not they were cued by another agent, but that they assign particular value to objects that were the targets of others' attention, and demonstrate their memory for those objects through a familiarity preference. This suggests two orthogonal influences on object memory. First, assigned value (when objects were cued by others) manifested as a preference to look at this object when it was encountered again. Second, in the absence of any particular reason for assigning it value (uncued objects), infants manifested their encoding as a novelty preference when it was encountered again.

Abstract 4, Title: Temporal Neural Dynamics of Infants' Sociomoral Evaluations

Abstract 4 Text:

Behavioral studies have shown that preverbal infants prefer prosocial over antisocial characters, suggesting that the ability to sociomorally evaluate others emerges early (for review/discussion see Woo et al., 2025). Using event-related potentials (ERP), prior work has implicated social—rather than purely attentional—processes in infants' responses to prosocial versus antisocial individuals (e.g., Gredebäck et al., 2015; Tan & Hamlin, 2022). However, studies to date have revealed inconsistent results (e.g., greater responding to helpers (Gredebäck et al., 2015) versus hinderers (Tan & Hamlin, 2022), relied on a single prosocial/antisocial interaction type (helping someone climb a hill), and have utilized experiment-level average effects rather than trial-level dynamic ones. Thus, to test the stability and generalizability of past findings as well as to explore the temporal dynamics of neural responses to prosocial versus antisocial individuals, we ran a pre-registered study in which infants watched a character be helped and hindered in its attempts to open a box (Hamlin & Wynn, 2011; Figure 1).

In a block design, 6- ($n=36$) and 12-month-olds ($n=37$) viewed alternating helping and hindering events followed by a series of still images of the helper or the hinderer. ERP analyses focused on two components of interest: the P400 (250–400ms, occipito-temporal cluster) indexing social processing, and the Nc (400–600ms, fronto-central cluster), indexing attentional processing.

Consistent with Tan and Hamlin (2022), preregistered average-level ERP analyses revealed a main effect of age, with higher amplitudes for the 12-month group than the 6-month group for both the P400, $F(1, 64) = 34.16, p < .001, \eta^2 = .30$, and the Nc component, $F(1, 62) = 28.53, p < .001, \eta^2 = .315$. Notably, P400 amplitudes were greater for hinderer ($M = 9.57, 95\% \text{ CI } [7.59, 11.50]$) than helper images ($M = 7.70, 95\% \text{ CI } [5.49, 9.90]$), $F(1, 64) = 6.22, p = .015, \eta^2 = .09$, whereas no valence-related amplitude differences emerged for the Nc component (see Figure 2). These results suggest that infants differentiate prosocial and antisocial agents via social rather than attentional processes.

In addition, exploratory trial-level linear mixed-effects models examined how, within-participants, responses evolved over repeated exposure to helpers and hinderers. These revealed that whereas P400 amplitudes to helpers decreased significantly across trials ($b = -0.24, SE = 0.06, t(79) = -4.23, 95\% \text{ CI } [-0.35, -0.13]$), suggesting habituation, responses to hinderers did not ($b = -0.05, SE = 0.06, t(80) = -0.97, 95\% \text{ CI } [-0.17, 0.06]$), yielding a significant Condition $\times$ Trial slope-level interaction ($b = 0.18, SE = 0.04, t(12,726) = 4.04, p < .001$). In contrast, Nc amplitudes decreased significantly (less negative) to both helpers ($b = 0.21, SE = 0.04, 95\% \text{ CI } [0.12, 0.29]$) and hinderers ($b = 0.17, SE = 0.04, 95\% \text{ CI } [0.08, 0.25]$), revealing no significant slope-level interaction, $p > .05$ (Figure 2).



These results offer insight into the early emergence of humans' sensitivity to prosocial and antisocial behaviors/agents, replicating past work revealing valence-asymmetric patterns of response in social, but not in attentional, ERP components using a new paradigm. Critically, by incorporating novel trial-level statistical techniques, these findings advance beyond past work by suggesting that, like adults', the infant social brain prioritizes negative social information both overall and across time.

Symposium 5.5 - Dynamic interplay of manual and postural behaviours across timescales in early development

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Summary

Traditionally, research on infants' manual contact has focused on separate effects of single variables studied in isolation. Our symposium moves beyond this by asking how (or whether) posture reorganises manual contact moment by moment and across developmental change.

First, we examine whether and when manual contact is shaped by the interaction between body position and object properties during free-flowing laboratory play. Second, using daily home videos, we assess whether walking and non-walking infants handle objects differently. Finally, we explore the functional purpose of manual contact by analysing how emerging walking reorganises infants' use of environmental elements during laboratory free-play.

Together, we offer three complementary perspectives spanning multiple time scales, ages, postural abilities, and methodological approaches, with the discussant linking the findings to broader cross-cultural contexts.

Details

Abstract 1 Title: Manual sampling in free-flowing play: real-time interaction between body position and object in 4, 6, and 9-month-olds

Abstract 1 text:

Extensive evidence suggests that infants manually handle (sample) objects differently depending on their physical state, e.g., body position (Adolph & Hoch, 2019), and object properties, e.g., size (Fagard & Pezé, 1997). Previous research examined these factors separately in tightly controlled settings. Building on insights from the structured designs, we explore how the object properties and body position interact in less controlled conditions. In the current study, infants were examined during free-flowing play at two time points: (1) at 4 and 6 months, when infants primarily



assumed prone and supine positions, and (2) at 9 months, when independent sitting predominated. The primary objective was to examine how body position and object properties jointly shape manual sampling when infants are free to choose their body positions and an object to sample.

Based on prior structured research, we expected that (1) 6-month-olds would sample objects more frequently and for longer durations than 4-month-olds (Rochat, 1989), and (2) at both ages, object type and body position would independently influence sampling frequency and duration (Libertus et al., 2013). For 9-month-olds, we hypothesised two main effects: (1) greater sampling frequency and duration while sitting independently (Soska & Adolph, 2014), and (2) that larger (stationary) objects would be sampled more frequently but for shorter durations than smaller (graspable) objects (Mash et al., 2014).

Participants were typically developing infants. Data were collected at three ages (48 infants completed all visits, 23 females): around 4 months ($n=54$, $Mdn=4.4$ months), 6 months ($n=74$, $Mdn=6.6$ months), and 9 months ($n=80$, $Mdn=9.0$ months).

Infants participated in free-flowing play sessions with their caregivers, and they were free to move and interact without constraints. Linear mixed-effects models analysed how infants' sampling duration and frequency varied with real-time combinations of body position and object.

Sampling frequency followed predictions from structured studies: 6-month-olds sampled more frequently than 4-month-olds ($F(1)=15.79$, $p<.001$), and 9-month-olds (Fig. 2a) sampled more frequently while sitting independently compared to other positions ($F(1)=51.91$, $p<.001$); or interacting with stationary objects compared to graspable ($F(1)=12.29$, $p=.001$). In contrast, infants sampled with varying durations depending on the interaction between object and body position (and age) at 4 and 6 months ($F(4)=2.52$, $p=.039$; Fig. 1), and also at 9 months ($F(1)=28.09$, $p<.001$; Fig. 2b). At 6 months, sampling duration was more differentiated than at 4 months: infants sampled some objects for longer durations than other objects in both prone and supine positions. At 9 months, differentiation was robust: stationary objects were sampled for shorter durations than graspable ones across all positions, and graspable objects were sampled for the longest durations during independent sitting.

By examining infants in less controlled settings, this study shows that manual sampling emerges from dynamic, moment-to-moment interactions rather than from isolated factors, and these interactions change across development, underscoring the importance of considering how multiple interacting elements shape infants' behaviour.

Abstract 2 Title: Walking-Related Changes in Infants' Object Interaction Experiences throughout the Day



Abstract 2 text:

Coordinated visual-manual exploration plays a critical role in children's acquisition of object knowledge such as three-dimensional object perception (Johnson, 2010; Soska et al., 2010). Prior laboratory studies have linked infants' visual-manual object-interaction with their real-time postural experiences. For example, visual and manual exploration of objects co-occur more frequently when 5-to-7-month infants are sitting compared to when lying on their backs or bellies (Soska & Adolph, 2014). Moreover, after learning to walk, infants frequently held and visually explored objects while standing or walking despite the challenges to maintain upright balance (Heiman et al., 2019). However, prior studies employed laboratory free play and could not assess the developmental changes in infants' visual-manual object experiences in naturalistic settings across the walking onset. As infants improve in upright balance after the walking onset, it is likely that upright will become an important postural basis for infants' visual-manual object interaction.

The present study collected data from 44 infants through two 14-day sessions at 11 and 13 months old to examine whether learning to walk was associated with changes in infants' object experiences throughout the day. Caregivers received 10 smartphone notifications per day prompting them to record a 10-s video of their infants. We coded infants' body postures and extracted all the bouts when infants were sitting (whether independently or supported) or upright (standing, cruising, or walking independently). We also coded their real-time object interactions during these bouts and divided them into two mutually exclusive categories of either 'visual-manual' (i.e., manually exploring while looking at the object) or 'manual-only' (i.e., holding the object without looking) interactions. We used beta regressions to test whether the relative durations of the two interaction types across their total sitting and upright times changed across the walking onset.

Across age and walking status, infants spent $M = 3.90\%$ ($SD = 6.71$) of their upright time in visual-manual object interactions and $M = 23.45\%$ ($SD = 16.17$) in manual-only interactions. Both interaction types were more frequent while sitting: 9.05% ($SD = 6.80$) in visual-manual and 37.69% ($SD = 13.95$) in manual-only interactions. Walkers spent a larger share of their upright time engaging in manual-only object interaction compared to non-walkers ($\beta = 0.44$, $95\% \text{ CI} = [0.20, 0.67]$). However, the duration of visual-manual object interactions while upright did not significantly differ by walking status ($p > .908$). Neither manual nor visual-manual exploration differed according to walking within the sitting posture ($ps > .306$). Consistent with prior findings, our results showed that after learning to walk, infants immediately incorporated manual skills with objects into newly learned upright balance skills (Heiman et al., 2019). This walking-related change in their daily object experiences was likely driven by manual-only interactions such as object carrying or sharing (Karasik et al., 2011, 2012), while daily coordinated visual-manual object interactions, on the other hand, rely primarily on sitting, and therefore were not significantly changed by the walking onset.

Abstract 3 Title: Tiny hands, big transitions: Analyzing crawling infants' target interactions during play as they learn to walk



Abstract 3 text:

Infants' action patterns change frequently and sporadically during play and undergo further changes after learning to crawl and walk. We used network analysis to track infants' shifts from one target to another during free play sessions held during the transition from pre-walking (Pre-W) to walking (W). This approach captures complex, rapidly changing behaviors in the form of connection patterns and what these connections mean. We tracked 13 infants in biweekly 10-min lab free play sessions with mothers present, until infants had ~2.5 months of walking experience. Current analyses involve 4 infants, with more forthcoming. We video-coded targets of interaction in Datavyu as follows: hands in the air, touching the ground, the mother, objects, furniture, or themselves. Lag-sequential analyses were used to create frequency matrices showing how often infants shifted from target to target. We then used SocNetV to create networks and compute density and centrality for Pre-W and W sessions for each infant. Preliminary results showed that infants were active and contacted targets 41-182 times/session. The infants spent more time contacting objects and furniture than themselves or the ground. Across the Pre-W and W transitions, contacts with the mother typically declined. Network density was consistent over time ($M = 1.1$), meaning the proportion of actual connections out of possible connections between targets were similar. To understand the importance of different targets within the networks, we examined three centrality measures: degree, betweenness, and eigenvector centrality (DC, BC, and EVC, respectively). Targets high in DC have many direct connections to other targets. Among all infants, objects were the highest in DC. Targets high in BC act as bridges, creating connections to other targets. They impact network efficiency, and their removal could disrupt connectivity between targets. For many infants, the ground and their mothers scored higher in BC but seemed to shift towards objects once walking skills improved. Targets high in EVC are notable because of their neighboring targets' importance. Infants' touches to themselves and their mothers scored highest in EVC. Centrality measures showed how various targets in the environment were influential to play in different ways. To further examine this, we assessed with which specific target infants sustained contact the longest. We examined how long infants maintained contact with each target, excluding moments when their hands moved to the air or ground. For Pre-W and W periods, we identified the top two targets with the longest sustained interactions. There was variability among infants, but most sustained interactions with the stairs in Pre-W sessions and most engaged with the pull phone during W sessions. In conclusion, infants use the environment around them to learn and build knowledge through play, and predominant contacts with objects and furniture may help infants learn about their own actions and their surroundings. Continued analyses will include how target properties affect contacts and sustained interaction, including the types of interaction they elicit (e.g., portability; climbability), how detailed they are, attention-holding features (e.g., music, lights), or whether they enable infants to learn and practice new skills (e.g., aim, balance, etc.).

Symposium 5.6 - Infant attention and cognition in context: the role of caregivers and broader social experiences

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Summary

Infants' social context shapes cognitive development by guiding their attention and creating opportunities for learning. This symposium integrates work that investigates mechanisms linking variability during infant-caregiver interactions and within infants' broader social contexts to early attention and cognitive development. We show that dynamic fluctuations in the predictability of caregiver behavior (Paper 1) and caregiver sensitivity (Paper 2) guide infants' attention. We then expand focus to social and language contexts, demonstrating that early social networks relate to infants' attention biases to caregiver faces (Paper 3) and bilingual language exposure shapes emerging perspective taking skills (Paper 4). Overall, these studies use multiple measures (EEG, behavioral coding, eye tracking, live interaction) across geographic and cultural groups to show that early attention and cognitive skills are shaped by dynamics at multiple levels of infants' surrounding social context.

Details

Abstract 1, Moment-to-moment fluctuations in caregiver entropy shape the temporal dynamics of infant attention and statistical learning later in infancy

Early cognitive development is related to how predictable an infant's caregiver is (Davis et al., 2017), but the exact mechanism driving this relationship is unknown. One possibility is that caregiver predictability shapes cognitive development by first shaping infant attention: infants might use regular interactions with their caregiver to learn when to attend to predictable information in service of learning, with downstream consequences for the development of general learning mechanisms. To test these ideas, we recorded naturalistic dyadic interactions between 2-6-month-old infants and their caregivers in South Africa and Malawi (N=222). Then, we hand-annotated infant attention (looking at caregiver) and five caregiver behaviors frame-by-frame, to measure how predictable caregivers were by calculating the entropy (Shannon, 1948) of their transitions between different behaviors.

Our first question was whether caregiver predictability shapes the temporal dynamics of infant attention. To ask this, we measured caregiver predictability in two contexts (with and without toys present). Our results show that caregiver behavior is shaped by context, such that the least predictable behaviors were different with and without a toy present: caregiver entropy following vocalizations was higher without a toy present ($t(114) = -2.70$, $p < 0.01$, Cohen's $d = -0.34$), while entropy following object holding was higher with a toy present ($t(96) = 4.44$, $p < 0.001$, Cohen's $d = 0.60$). Impressively, infant looking was tightly yoked to the most informative (highest entropy) signal in each context. There was also a significant quadratic relationship between caregiver entropy and infant looking ($t = -3.02$, $p < 0.01$) across time within-dyad, such that infant looking was highest when caregivers were slightly more predictable than their own average. Both these results suggest infants look at their own caregiver when she is providing information which is useful for their learning, and show that context-to-context and moment-to-moment fluctuations in caregiver predictability shape infants' early attention, regardless of the cultural context an infant is in.



Our second question was whether differences in caregiver predictability also shape the neurodevelopment of specific learning processes. We reasoned that statistical learning, a learning mechanism which allows infants to learn about predictable information, might be particularly sensitive to differences in the predictability of babies' early environments. Thus, six months after their first visit, a subset of families (N=103) returned to participate in an auditory statistical learning task during EEG. We found evidence of learning-related change in infants' neural responses to predictable information during the statistical learning task. The magnitude of statistical learning-related change in infants' EEG responses was associated with the predictability of their caregivers' vocalizations several months earlier, such that infants with more predictable caregiver vocalization patterns showed more evidence of statistical learning later in the first year of life ($F(1,79) = 4.72, p = 0.03$).

These results together suggest that early experience with caregiver predictability shapes later learning, providing support for the hypothesis that caregiver predictability is related to cognitive development because caregiver predictability shapes the neurodevelopment of core learning and memory systems during key developmental windows.

Abstract 2, Dynamic associations between caregiver sensitivity and infant sustained attention during play

Early caregiver-infant interactions provide critical scaffolding for infant attentional development and learning. Sensitive and temporally contingent parental responses¹ are associated with higher joint attention², which in turn facilitates infant learning across developmental domains³. However, most prior research relies on global or aggregated assessments of sensitivity and attention, obscuring potentially meaningful within-dyad variability that infants experience in real time. Infants' attention is inherently dynamic, and caregiver sensitivity may support or redirect attentional engagement precisely through these moment-to-moment fluctuations. Consequently, it remains unclear whether transient increases in sensitivity during an interaction correspond to parallel changes in infants' sustained attention. We address this gap by examining both between-dyad differences and within-dyad, moment-to-moment associations between caregiver sensitivity and infants' sustained attention during a free-play interaction, providing insight into how broader tendencies and narrower, real-time fluctuations in sensitive caregiving relate to early infant attention and development.

Caregiver-infant dyads ($n = 86$) recruited in an ongoing study of early development and experience engaged in 10 minutes of free play interactions when infants were 12 months of age. Coders were trained to reliability and rated caregiver and child behaviors during the free play using the Parent-Child Interaction Rating Scales. The present study focuses on codes for caregiver sensitivity, or behaviors indicating tending to and being aware of a child's needs, cues, and interests, and infant sustained attention, or persistence towards an activity or a toy. To capture meaningful temporal variation, the play session was divided into sequential two-minute epochs prior to coding. This structure allowed us to distinguish (a) associations between overall caregiver sensitivity and overall infant attention across the interaction, (b) within-dyad effects capturing whether infants displayed higher attention during epochs when caregivers were more sensitive than their own average level, and (c) lagged effects testing whether caregiver sensitivity in one epoch predicted



infants' attention in the subsequent epoch. Linear mixed-effects models were used to accommodate repeated measurements nested within infants.

Across all models, sensitivity was associated with infant sustained attention. Higher caregiver sensitivity on average was statistically significantly associated with sustained attention across the play session ($b = 0.35$, $p < .001$). Within dyads, epochs characterized by greater sensitivity relative to the caregiver's average level were associated with correspondingly higher infant sustained attention ($b = 0.10$, $p = .002$), indicating that moment-to-moment increases in sensitivity map onto increases in children's attentional engagement. Lagged analyses further showed that caregiver sensitivity in one two-minute epoch was statistically significantly associated with infants' sustained attention in the next epoch ($b = 0.24$, $p < .001$), suggesting that sensitive caregiving within a single interaction is related to later child attention.

Together, these findings demonstrate that sensitive caregiving supports infants' sustained attention and persistence at both the trait-like and momentary levels. By capturing temporal fluctuations that previous designs obscure, this study reveals dynamic, time-ordered links between caregiver behavior and infant engagement and underscores the immediate and foundational role of sensitivity in scaffolding early attentional processes central to learning and development.

Abstract 3, Social Networks Influence Early Development of Infants' Attention Orienting to Caregiver vs. Stranger Faces

Infants rely on attention skills to orient to and hold focus on social partners (Leppänen, 2016). Infants rapidly develop attention biases towards faces in the first month of life and very young infants preferentially look at their caregivers compared to strangers (Field et al., 1984). Some evidence suggests that infants may show increased biases to attend to stranger faces after 6 months (Barrera & Mauer, 1981). However, these findings have been mixed and the mechanism underlying these changing attention biases remains unclear. While infants initially see their caregiver's face most often, they increasingly see strangers' faces over the first year (Sugden & Moulson, 2019). Furthermore, variability in infants' broader social networks has been related to their attention biases to familiar vs. unfamiliar face categories (Arnold et al., 2024). These findings suggest that variability in infants' emerging social networks may similarly shape the development of attention biases to caregiver and stranger faces.

Infants and their caregivers completed two sessions at 4- (NPrelim = 94) and 6-months (NPrelim = 73). We assessed social network size using the Child Social Network Questionnaire (Burke et al., 2022), measured as the total number of unique people and groups the infant experienced within the past two weeks. We also recorded infants' eye movements as they viewed 6-item search arrays across two trial types (Figure 1). During single-target trials the array included one face (caregiver or stranger) surrounded by distractors. Dual-target trials included two faces (caregiver and stranger) to mimic the design of visual paired comparison tasks that previously identified attention biases to caregiver faces. Selective attention demands therefore varied across trial type, as this concurrent presentation during dual target trials increased competition between the two faces. We measured frequency and speed of initial orienting and duration of looking to the faces.



At 4 months, both social network size and trial type influenced frequency of orienting to faces, with no effects of face identity. Infants with smaller social networks were more likely to orient to any face when only one appeared, compared to trials with both faces ($p < .001$). Those with larger social networks showed similar orienting to faces across trial types ($p = .75$). At 6 months, social network size, trial type, and face identity influenced speed of orienting to faces (Figure 2). There were no differences in orienting when only one face appeared (p 's $> .30$). When both faces appeared, infants with smaller social networks oriented faster to stranger faces ($p = .02$), whereas those with larger social networks oriented faster to caregiver faces ($p = .02$).

These results show that younger infants' orienting to faces was driven by task demands and their broader social experiences. Effects of specific face identity emerged with age, but social context and task demands also remained important. Overall, these results suggest that there are multiple factors that influence developing attention biases to caregiver and stranger faces, including the immediate demands of the task context and the broader context of infants' daily social experiences.

Abstract 4, Exploring Links between Language Exposure and Infant Perspective-Taking: A Replication of Liberman and Colleagues (2017)

Background:

Diverse language environments have been associated with enhanced perspective-taking and social communication (see Gampe et al., 2019; Singh et al., 2024). Our preregistered study (osf.io/zrmp) replicates Liberman and colleagues (2017), where they found that 16-month-old children growing up in multilingual homes ($>5\%$ exposure to another language in the home) showed better perspective-taking skills on a barrier task. Expanding on these findings, we predict that we would also find differences in perspective-taking between monolingual and bilingual infants ages 14 to 16 months.

Methods:

Fifty-nine 14- to 16-month-old ($M_{age} = 471.9$ days, $SD = 27.11$, 26 girls) monolingual ($n = 41$) and bilingual ($n = 18$) infants are included in this replication of the Liberman et al. (2017) barrier task. Data collection is ongoing and we will test another 40 participants for the final sample. Infants were seated on their parent's lap for the duration of the task. A barrier was placed on the table between the primary experimenter and the infant on the other side of the table. The barrier placement was counterbalanced. The task consisted of two conditions, the identical toy and the different toy condition (see Figure 1). First an experimenter placed the two items (identical or non-identical) in front of the child. In both cases, the primary experimenter asked for the object that they could see that was not behind the barrier. If the child was able to take the perspective of the experimenter, the infant should only give the experimenter the mutually visible object.

Results:

Trials were coded as correct if the infant chose the item that was visible to both the experimenter and the child on the identical and non-identical trials (see Figure 2). We did not count trials where



the infant response was ambiguous or if they reached for both objects on that trial. Both monolingual and bilingual infants did not perform significantly above chance ($p < .001$) on the proportion correct on identical and non-identical trials. Bilingual infants showed a marginal trend toward above chance performance on identical trials, but this did not reach significance, $t(17) = 2.05$, $p = .056$). Welch two sample t-tests showed there were no differences between monolinguals and bilinguals on identical, $t(49.92) = -0.32$, $p = .75$ and non-identical trials, $t(33.42) = -0.76$, $p = .45$). Only the bilingual group showed some evidence of perspective-taking. It is important to note that we define an infant as bilingual if exposed to at least 20% of a second language (L2) as opposed to the 5% cutoff in the original study. Findings with the 5% cutoff show no differences between monolinguals and bilinguals. We will also conduct a regression using a continuous measure of second language exposure and will include other contextual parameters, such as sleep quality, on outcomes. Finally we will use multilevel modeling logistic analysis to assess correct and incorrect performance across trials (see Rocha Hidalgo et al. (2022) for a similar approach) to examine whether additional individual differences contribute to the pattern of results.

Symposium 6.1 - Temporal and multimodal dynamics of caregiver-infant communication

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Summary

Caregiver speech unfolds in real time, shaped by infants' behaviors and the objects around them. This symposium brings together four cutting-edge approaches to examine the *moment-to-moment dynamics* of caregiver input and how this input guides infants' attention and learning. Presentations 1 and 2 reveal that caregiver speech varies by the type and location of objects in ways that guide attention and shape vocabulary exposure. Presentation 3 investigates how caregivers' communication is related to their infants' multimodal behaviors. Presentation 4 demonstrates that the temporal alignment of language input with infants' actions can be manipulated to support word learning. These multi-method studies demonstrate how early communicative environments emerge from the dynamic coordination between caregiver input, infant behavior, and the immediate physical context, providing new insights into how everyday interactions shape language learning.

Details

Abstract 1, Title: Parents structure language differently across play contexts: Frequency and burstiness of object, spatial, and action words

Introduction

Caregivers' speech to young children varies across contexts, with routines like mealtime, bathing, and dressing involving less talk but greater lexical specificity related to food, clothing, and body parts compared to play (e.g., Soderstrom & Wittebolle, 2013; Tamis-LeMonda et al., 2019). Less is known about differences between play activities (e.g., O'Brien & Nagle, 1987), despite the fact that different play materials afford different opportunities for exploration. Moreover, the temporal



structure of parental speech varies, with repetition of words and phrases in close temporal clusters and across longer delays (e.g., Suanda et al., 2016). The temporal clustering of parents' speech predicts infants' learning of novel words (Slone et al., 2023). The current study predicted that the frequency and temporal structure of parents' use of specific linguistic content (e.g., object, spatial, and action words) would vary as a function of play activity.

Method

We observed 71 English-speaking 9-month-old infants and their parents from a racially and ethnically diverse, middle-class North American community. Dyads sat side-by-side at a table and engaged in two three-minute play sessions with age-appropriate toys, one a puzzle and the other, an activity board with gears, buttons, and switches. Parents' speech was transcribed, timestamped, and coded for object, spatial, and action words. We computed words per minute to account for variation in the duration of the play sessions.

Results

Mixed-effect models revealed that parents' use of object, action, and spatial words differed by context. During puzzle play, parents produced more object words than action words, $p < .001$, and the number of spatial words was similar to both object and action words. During activity board play, action words were most frequent, $ps < .001$, whereas spatial and object words occurred at comparable, lower levels. Comparison of the two play contexts revealed that parents used more object and spatial words during puzzle play than activity board play, $ps < .001$, while action word use did not differ. Thus, the puzzle play induced more spatial and object words, and action words were used similarly across activities.

The temporal structure of parents' speech between the two activities also differed. Parents rarely repeated individual words during activity board play, whereas repetitions were common during puzzle play. We examined the temporal structure of parental speech during puzzle play by calculating inter-onset intervals (IOIs) for repeated uses of the same word and computing the burstiness metric B (Kim & Jo, 2016) for each parent for each object, spatial, and action word. As seen in Figure 1, during puzzle play, parents' use of object words was bursty as indicated by B significantly greater than zero, $t(41) = 4.682$, $p < .001$. However, parents' use of spatial and action words was random, as indicated by B not significantly different from zero. Thus, the timing of these word types also vary.

Conclusion

These findings highlight how play materials shape both what parents say and when they say it, revealing contextual variability in the micro-temporal structure of early language environments.

Abstract 2, Title: Demonstratives as a multimodal pathway to early word learning

All languages have demonstratives: grammatical words such as THIS and THAT or HERE and THERE in English. Understanding their acquisition is important because they are highly frequent in parent-child interactions and form a foundational grammatical class crucial for establishing joint attention. They are also among the first 50 words children produce across languages. Adult



demonstrative use relies on spatial and social cognition since speakers need to monitor both the location of the intended referent and the attention focus of the listener. This creates an interesting puzzle for demonstrative acquisition since young children need to learn the spatial and attentional contingencies of these grammatical words.

In the current study, we quantified the kind of demonstrative input children receive in a naturalistic toy play interaction. Specifically, we aim to better understand (i) how demonstrative use changes as a function of the object's position in relation to the parent and child locations and (ii) how parents use demonstratives in real time to guide children's attention, including the *temporal dynamics* of these interactions—whether the child's gaze shifts before, during, or after the parent's demonstratives use—revealing how demonstratives function as moment-by-moment attentional cues.

We used an existing naturalistic parent-child toy-play dataset. In this dataset, English-speaking parents and children (19.3 m.o.) were provided with 10-24 toys to play with for 15 minutes (Fig.1A). Parent and child each wore a head-mounted eye-tracker, providing rich moment-by-moment gaze data (Fig.1B). We first extracted all the moments when parents used THIS/THAT to refer to a toy identifiable in the child's view. We coded the referent's relative location (i.e. close to parent or child) and derived real-time attentional measures of whether the child looks at the intended referent before/during/after the demonstrative.

We found that (i) parents frequently use demonstratives in everyday play interaction. Parents use THIS more often for objects close to them and THAT for objects close to the child (Fig.2A), suggesting that even when parent and child are in relatively close proximity, parents' demonstrative use changes as a function of referent position as well as speaker and listener locations, providing critical input for children to distinguish near and far space. (ii) Demonstratives are useful tools for guiding/maintaining children's attention to the intended referent (Fig.2B). When parents used THIS, infants' looks to the target object began to rise shortly before hearing the word and peaked around 1.5 seconds after the word, suggesting that THIS moments effectively cue infants to attend to a new or highlighted referent. In contrast, when parents used THAT, infants were typically already fixating on the target object well before the word onset and maintained their gaze following the utterance, indicating that THAT moments are often used to comment on an object the infant is already attending to.

Our findings suggest that demonstratives are not only a linguistic universal, but a universal tool for early word learning. By activating a multimodal pathway that integrates language, attention, and social interaction, demonstratives create structured moments that scaffold learning long before infants master language.



Abstract 3, Title: The distribution of infants' vs. caregivers' multimodal communicative behaviors

Caregivers and infants communicate through many modalities beyond speech. Previous work has shown that when infants use two communicative modalities (e.g., speech and gesture together), caregivers are more likely to provide a bimodal response (van der Klis et al., 2023). However, little is known about how infant-caregiver dyads do or don't shape each other's multimodal behaviors. In an at-home, naturalistic study, we investigated five multimodal behaviors of infants and caregivers to understand how dyadic communication unfolds.

We coded five infant multimodal behaviors (vocalizations, action, gesture, emotion, and touch) in a corpus that was initially coded for caregiver behaviors (Kosie et al. 2024). We predicted (H1) that individual variability in caregivers' multimodal behavior would be related to their infants' multimodal behavior. Additionally, we predicted (H2) that individual variability in infants' multimodal behavior would be related to infants' vocabulary size.

Infant-caregiver dyads ($n=44$, $M^{age} = 20.48$, $SD^{age}=1.87$) were recorded at home for a 10-minute free play session over Zoom. Infant vocabulary was assessed concurrently and 10 months later via the MacArthur-Bates Communicative Development Inventory (MCDI; Fenson et al., 2007). This study represents a preliminary analysis of $n=35$ (17 female) of the infants' multimodal behaviors. Their behaviors were annotated using ELAN and showed high interrater reliability ($ICC>0.87$).

Infants varied in their total proportion of time engaging in any one of the five communicative modalities (range=0.19–0.71, $M=0.46$, $SD=0.14$); the coefficient of variation ($CV=0.31$) indicated considerable individual differences. For caregivers and infants, actions and vocalizations had the largest proportions. In contrast, infants spent a larger proportion of the interaction performing actions than vocalizing (**Figure 1**). Caregiver proportions of behaviors were not significantly correlated to their infants' for any individual behavior or in aggregate (all $ps > 0.1$).

Linear regression models revealed that infant vocalizations were significantly related to infant productive vocabulary at the time of the play session ($\beta=9.23$, $p<.001$, $\eta^2=0.37$). Adding other modalities to a vocalization-only model did not significantly improve the prediction of vocabulary at either time point (T1: $F(4,29)=2.58$, $p=.058$; T2: $F(4,25)=1.95$, $p=.133$) (**Figure 2**). Interestingly, the proportion of infant emotion (laughing and crying) showed a negative association with infants' concurrent ($\beta = -47.28$, $p=.016$, $\eta^2=.18$) and longitudinal vocabulary ($\beta=-77.85$, $p=.020$, $\eta^2=.20$). This converges with Kosie et al.'s (2024) finding that the caregivers' use of emotion was correlated with lower infant vocabulary scores.

These findings demonstrate that infants vary widely in their multimodal communication, but counter to our hypothesis, caregiver communicative behaviors were not related to their infants'. Emotion, but not other behaviors, was related to infants' vocabulary size. These results suggest that caregivers and infants deploy multimodal behaviors during natural interactions in ways that are largely independent of one another's communication patterns. Our immediate next steps are to



examine the temporal dynamics of caregiver-infant interaction, including turn-taking patterns across multiple modalities of behavior.

Abstract 4, Title: Experimentally testing whether word-action correspondence supports noun learning

During daily life, infants hear words about their actions. The literature is replete with studies connecting infants' real-time actions to caregivers' language (e.g., caregiver says "car" as infant pushes a car). Researchers hypothesize that word-action correspondence disambiguates a word's meaning, supporting learning (e.g., if infant hears "car" while pushing a car, the action may spotlight the referent). However, experimental evidence is needed to test whether such correspondences indeed facilitate word learning.

We experimentally manipulated the word-action correspondence of language input and measured the effect on noun learning. We recruited $N = 75$ infants ($M = 34.6$ months, $SD = 3.5$). The study had two phases: a play session and test trials. During the play session, the infant and experimenter played with five novel "toys" with novel names (e.g., "dax", "modi") for 5 minutes.

The critical manipulation was *how* the experimenter named the toys during the play session. Infants were semi-randomly assigned to one of three groups. In the action cues group, infants heard nouns in sync with their actions. That is, the experimenter named each toy as the infant spontaneously manipulated it ("the dax is green" as infant held the dax). Each infant in the action cues group was then paired with two yoked control infants, who heard verbatim the exact same words at the exact same times (but, critically, the input was not contingent on the control infants' actions). In the social cues control group, the experimenter gestured and looked to the target toy as it was named ("the dax is green" as the experimenter points to dax). In the no cues control group, the experimenter named the toys without context cues (i.e., the infant only had the utterance frame to help decipher word meanings).

Afterwards, we tested whether infants learned the nouns across 15 test trials. Infants in the action cues group performed the strongest, learning $M = 3.22$ ($SD = 1.75$) words, with $M = 78\%$ ($SD = 22.36$) of trials correct overall. The social cues control group showed an attenuated pattern of learning, with $M = 1.50$ ($SD = 1.56$) words learned and $M = 51.67\%$ ($SD = 22.67$) of trials correct. In contrast, the no cues control group performed poorly on test trials; $M = 1.18$ ($SD = 0.58$) words learned, 33.35% of trials correct.

To further probe learning mechanisms, we coded infants' visual attention to the toys during the play session. Infants in the action cues group were nearly always looking at the toy before ($M = 98.28\%$, $SD = 2.83$) and after ($M = 87.81\%$, $SD = 5.39$) it was named. Infants in the social cues group frequently shifted their attention to the object after it was named (presumably, in response to the gesture; from $M = 57.33\%$ to 85.94% ; $SDs = 15.11, 5.52$). In contrast, the no cues group coordinated their attention to target object much less often ($M's = 41.57\%$ and 42.19% ; $SDs = 14.7, 5.49$).



Symposium 6.2 - Origins and development of rhythm processing in early infancy: What we know and critical questions for future research

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Summary

The ability to track rhythmic input is critical for music, language, and social development, yet the mechanisms underlying these relationships are poorly understood. Using divergent methods (neural rhythm tracking, representational similarity analysis, predictive coding, eye tracking) the talks in this symposium explore the emergence and development of prenatal neural tracking of auditory rhythms; the nature of categorical rhythmic representations in newborns in comparison to adults; the primacy of timing over pitch expectations in early infancy; and how the rhythms of infant-directed speech and song differentially guide visual attention to faces over the first year after birth. In combination, the talks integrate how early auditory rhythmic processing abilities develop and scaffold auditory-visual attention underlying learning, language and social development, while outlining important directions for future research.

Details

Abstract 1 Title:

The impact of tempo on early auditory rhythm tracking: Evidence from electrophysiological data during the third trimester of human gestation

Abstract 1 Text:

Auditory processing emerges remarkably early, beginning in the late second trimester of gestation. Rhythm experience starts in fetal life, shaping neural capacities critical for cognitive development. Both music and language share hierarchical periodicities at multiple timescales, whose encoding is essential for perception and interaction. How the brain begins to encode these regularities and their developmental trajectory remain poorly understood.

Our previous findings demonstrate that encoding rhythmic periodicities develop progressively during the third trimester of gestation with early neural tracking of fast periodicities and later emergence of neural tracking of slower periodicities. Here, we address the impact of tempo (cycle duration) and metrical hierarchy (beat groupings) on neural synchronization to rhythmic periodicities in early development. Using high density electroencephalography, we recorded neural activity in 25 neonates and 20 adults while they listened to simple rhythms presented at different tempi. We then evaluated neural tracking of different periodicities present in the rhythms using a stimulus-brain synchronization index and compared them across tempi and also developmental stages (neonates versus young adults).



Our results show that neural synchronization to auditory rhythms occurs across multiple frequencies. However, it varies systematically with tempo and development. More precisely, in neonates, tempo predominantly orchestrates neural tracking, whereas in adults, the metrical hierarchy significantly shapes neural responses to rhythm. It is yet to be determined how endogenous neurodevelopment during the prenatal period and its possible interaction with exogenously driven rhythmic experiences can shape early neural responses. We discuss hypotheses on how endogenous neurodevelopment and the evolution of neural interactions might influence the developmental trajectory of rhythm processing and how these mechanisms can prepare the developing brain for the processing of exogenous rhythms.

Abstract 2 Title:

Evidence for neural categorization of rhythm in human newborns

Abstract 2 Text:

Humans show an outstanding capacity to perceive, learn, and produce musical rhythms. These skills rely on mapping the sheer diversity of possible rhythmic sensory inputs onto a finite set of internal rhythm categories. What are the brain processes underlying rhythm categorization? One view posits that rhythm categories might be at least partially rooted in neurobiological predispositions constraining the internal representations of rhythmic inputs. At the same time, a growing body of work suggests that rhythm categorization is plastic, open to be shaped by experience over the course of life. However, whether rhythm categorization is already in place at birth, and if so, in what shape, has so far remained a longstanding question. To investigate this, we measured neural responses to rhythm in healthy full-term human newborns, capitalizing on their minimal post-natal experience.

Scalp electroencephalography (EEG) was recorded from 0- to 3-days-old newborns while they were exposed to acoustic sequences consisting of repeating patterns of two inter-onset intervals ranging from isochrony (1:1 interval ratio) to long-short patterns (2:1 ratio). In a second experiment, we separately recorded neural (EEG) and behavioral (sensorimotor synchronization) responses to the same rhythms in adult participants. The data were analyzed using a novel approach combining frequency-domain and representational similarity analyses.

Our results indicate that human newborns, only a few days after birth, already exhibit neural representations consistent with rhythm categorization. Moreover, the representation of rhythm measured in newborns significantly correlates with the representational geometries recorded in adult participants. Altogether, these findings show that internal representation of rhythm may be biased towards categorical structures by neurobiological predispositions already in place at birth. These early processes likely form a scaffold upon which experience later shapes rhythm perception and production, linking the biological roots of temporal processing to the diversity of music practices encountered around the world.

Abstract 3 Title:



Human newborns form musical predictions based on rhythmic but not melodic structure

Abstract 3 Text:

The ability to appreciate and engage with music develops spontaneously and universally across cultures. This ability is supported by sequencing and anticipatory processes that track structural regularities concerning two main sound dimensions: timing and pitch. Surprisingly, however, it is unclear to what extent this ability is already developed at birth. Here, we used ecologically valid musical stimuli (pieces composed by J. S. Bach) to assess if the neural encoding of both timing-related and pitch-related structural regularities, as observed in adults, is already present at birth. We recorded EEG from N = 49 two-day-old newborns whilst listening to the original pieces (real condition) and control stimuli with shuffled tones and inter-onset intervals (shuffled condition). We used computational modeling to quantify context-based rhythmic and melodic probabilistic expectations. We then used multivariate Temporal Response Functions to isolate these high-level brain processes, whilst dissociating them from low-level acoustic tracking, such as local changes in timing and pitch.

Probabilistic *rhythmic* expectations were neurally encoded only in response to real but not shuffled music, demonstrating that newborns rely on rhythmic statistical regularities to generate musical expectations. We found no evidence for tracking *melodic* information, demonstrating a downweighing of this dimension compared to the rhythmic one.

This study provides neurophysiological evidence that the capacity to track statistical regularities in music is present at birth and driven by rhythm. The asymmetry between precocious rhythmic and slow-emerging melodic sensitivity suggests that these core components of human musicality do not emerge in parallel but follow distinct developmental timelines, with melodic tracking likely developing with later exposure to pitch-varying signals such as speech and music.

Abstract 4 Title:

How the rhythms of infant-directed music and speech guide visual attention to the face across the first year after birth

Abstract 4 Text:

Caregivers around the world naturally engage with infants using distinctive ways of speaking and singing, with modified acoustic characteristics compared to adult-directed productions. Although it is known that these early infant-directed (ID) interactions play a crucial role in building emotional and social connections, and in scaffolding language development, how they do so remains understudied. Recent evidence suggests, however, that the rhythms of ID songs help guide infants' attention to emotionally and socially relevant facial regions, with 2- and 4-month-old infants more likely to look at the caregiver's eyes at the time of the strong beats of the songs (Lense et al., 2022). In the present research, we are interested in four main questions. First, do the rhythms of ID speech entrain visual attention to the face similarly as for ID song, or do these two modes of communication give rise to distinct attentional patterns in infants? Second, does rhythmic entrainment to the face change between 4 and 12 months of age as infants learn language? Third,



do ID singing and ID speech engender similar facial looking patterns at 4 months, but become more differentiated by 12 months as infants learn language? And fourth, do infants show different looking patterns to native and non-native languages differing in rhythmic structure (examining stress-timed [English] vs. syllable-timed [Spanish] languages)?

In this longitudinal study, we present videos of ID singing and speech, both in English and Spanish, to English-learning infants in Canada and Spanish-learning infants in Spain at 4, 6, and 12 months of age, while recording their visual attention with eye tracking. To date, we have tested 26 English-learning infants at 4 and 6 months. Peristimulus time histograms indicate that, at 4 months, infants were significantly more likely to look at the eyes during the beat or stressed vowels in both speech and song. By 6 months, this entrainment pattern became even more pronounced for ID singing, but infants' visual attention was not aligned with the temporal structure of ID speech. In parallel to these discrete analyses, the findings were further supported by continuous analyses using temporal response function models based on three auditory features: gammatone envelope, spectral flux, and binary-coded strong beats or stressed syllables.

As data collection progresses, we will examine how the visual attentional effects of ID speech and song rhythms change between 6 and 12 months, and compare English- and Spanish-learning infants. Moreover, we will examine how each sensory domain in the videos (visual vs. auditory) contributes independently to visual-attention entrainment by using modified versions of the stimuli. By examining how ID speech and song guide infants' attention to faces over the first year after birth, we will contribute to understanding how the rhythms of ID speech and song to guide early language acquisition and social-affective skills.

Symposium 6.3 - Maternal factors shape early brain development: influences of maternal health and breastmilk on infant neurodevelopment

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Summary

Integrative Statement: Infant brains are wired to develop attachments to and learn about their caregivers. Even so, our understanding of how caregivers shape the developing brain remains limited. This symposium highlights innovative mechanistic research examining how maternal biology and psychopathology shape the developing infant brain. Talk 1 will elucidate (using both human infant and cellular data) how breastmilk functions as a conduit for maternal biochemical signaling and shapes the developing brain. Talk 2 demonstrates that maternal antibody transfer shapes newborn brain connectivity. Talk 3 demonstrates that maternal anxiety influences infant brain connectivity in ways that subsequently increase risk for developing anxiety. Across these talks, we show how a mother's breastmilk, biology, and psychology shape the infant brain. Together, this symposium will illuminate the profound impact of maternal health in shaping foundational infant neurobiology.

Details



Abstract 1, Title: How Milk Builds Brains – Cellular and Neuroimaging Evidence

Abstract 1 text: Milk has evolved to support all of a developing infant's needs. During the first six months of life, when infants are completely dependent on milk, the brain undergoes the most drastic growth that occurs postnatally. Despite an infant's reliance on milk during this time of foundational neurodevelopment, little is known about what and specifically how milk supports brain development. In this presentation I will present data from a cohort of typically developing infants (n=30) suggesting that milk components, including macronutrients, hormones, extracellular matrix proteins, and extracellular vesicular microRNAs (EV-miRNA), support brain growth during the first year of life, assessed using MRI at 3, 6, and 12 months old. This work confirms the roles of macronutrients (i.e., fats, carbohydrates, and protein) in brain growth. More complicated relationships exist for immune factors like C-reactive protein and interleukin-6. Other milk components, including osteopontin and nerve growth factor (NGF) also predicted brain growth. Interestingly, our findings replicate a large body of literature suggesting that white matter, the tissue comprised of the axons extending between cortical regions, is particularly sensitive to early nutrition. This consistent finding suggests that the cells responsible for wrapping axons in the fatty myelin sheet that provides their namesake color, may be impacted. These cells, specifically oligodendrocyte precursor cells (OPCs), are one of only a few neural cell types that migrate, proliferate, and mature during the early postnatal period. Our preliminary cellular studies show that the relationships observed between EV-miRNAs and white matter growth are likely due to impacts on cellular proliferation and maturation of OPCs. We are additionally pioneering the use of optically pumped magnetometer magnetoencephalography (OPM-MEG) to explore what brain function looks like while actively feeding, and how these patterns can be used to further explain brain development in the context of early nutrition. The ultimate goal of this line of research is to better support infant neurodevelopment through scientifically informed policies, and optimization of milk alternatives for infants that are unable to receive human milk.

Abstract 2, Title: Total Immunoglobulin G (IgG) antibodies during pregnancy correlate with infant salience network functional connectivity

Abstract 2 text: Introduction: Prenatal maternal immune activation (MIA) from infection is associated with the offspring's risk of neurodevelopmental disorders. Previously, we reported that exposure to 3rd trimester MIA via inflammation (interleukin-6 and c-reactive protein) is associated with perturbations in functional connectivity of the salience network (SAN) in neonates. The SAN, composed of the right and left insula and the dorsal anterior cingulate (dACC), is critical for detecting environmental stimuli, regulating neural activity that facilitates behavioral responses, and is altered in several neurodevelopmental disorders. However, it remains unclear how maternal antibody transfer relates to fetal brain development. A global index of total infection and long-term immunity—total immunoglobulin G (IgG)—can serve as a model for understanding how the maternal adaptive immune response affects the offspring's brain. As IgG comprises 70% of circulating antibodies and persists after active infection, it serves as an index of past infection and long-term protection against a microorganism. We hypothesize that prior maternal infection and an estimate long-term immunity (total IgG) during pregnancy is associated with SAN brain connectivity in infants.



Methods: Forty-four pregnant women participated in this study. They underwent blood draws during the 2nd and 3rd trimesters. Maternal serum was assayed for total IgG. Because total IgG was highly correlated across trimesters ($r > 0.80$), it was averaged across trimesters. Infants were scanned on a 3T GE scanner during natural sleep to collect fMRI data. Standard resting-state preprocessing was performed. To access SAN connectivity, seed connectivity from the dACC was used. For each infant, the time course from the dACC seed was extracted and correlated with the time course of all gray matter voxels, yielding a map of dACC functional connectivity for that infant. Voxel-wise linear models were used to examine associations between dACC connectivity and maternal total IgG during pregnancy. Multiple comparisons were corrected for using cluster correction and thresholded at $p < 0.05$, corrected.

Results: The majority of infants were male (68%) and were scanned at a mean postmenstrual age of 43.75 weeks. Maternal total IgG ranged from 588 to 1639 mg/dL, which are typical levels for an adult. Higher maternal total IgG is associated with stronger connectivity between the dACC and the right hippocampus, the right temporal lobe, bilateral mid cingulate cortex, and the left parahippocampus. Higher maternal total IgG is associated with weaker connectivity between the dACC and the left cerebellum.

Conclusions: Our results suggest that maternal antibodies associate with functional connectivity in the infant brain. Maternal IgG antibodies can cross the placenta and are the only class of antibodies that are significantly transferred from mother to fetus. As such, they provide a plausible pathway of how the maternal immune system can affect brain development in offspring.

Abstract 3, Title: Resting state functional connectivity associated with maternal anxiety moderates pathways from behavioral inhibition to anxiety

Abstract 3 text: One in four mothers experience high anxiety during the first postpartum year (Fawcett et al., 2019; Ogallar et al., 2025). While we know postpartum anxiety can alter the caregiving environment (e.g., Stein et al., 2012; Goodman et al., 2016), our understanding of how maternal anxiety influences the developing brain remains limited. Even so, many hypothesize that exposure to maternal mental illness could shape the infant brain in ways that increase the infant's susceptibility to develop mental illness themselves. The current study evaluates this hypothesis by (1) characterizing associations between maternal anxiety and infant resting-state functional connectivity (rsFC) and then (2) testing whether rsFC in the identified networks moderates early-life pathways to anxiety. Specifically, we focus on the pathway from behavioral inhibition (BI; a temperament characterized by avoidance of novelty) to anxiety. While infants exhibiting BI are more likely to develop anxiety than infants without BI, not all infants with BI ultimately develop anxiety disorders. Thus, we hypothesize that alterations in rsFC associated with maternal anxiety may amplify the association between BI and anxiety.



To evaluate this possibility, infants (N=49; Mage=4 months 26 days; range= 3.77 to 6.4 months) underwent resting state fMRI during natural sleep and mothers completed the Beck Anxiety Inventory. At 14 months, BI was observationally assessed. Between 4-6 years of age, child anxiety was evaluated using the Child Behavior Checklist. Network-level enrichment analyses were conducted to identify network pairs showing significant associations between maternal anxiety and infant rsFC (controlling for infant sex, age at scan, and mean framewise displacement). This analytic approach has been used extensively to study the developing brain (Wheelock et al, 2018; 2019; Filippi et al, 2024). Significance is determined using permutation testing paired with hypergeometric tests which accounts for the total number of significant correlations observed across the connectome and the total number of regions-of-interest (ROIs) within a network pair. Connectivity estimates from significant network pairs were then averaged and tested as moderators of the association between BI and anxiety.

Results showed that two network pairs exhibited significant associations with maternal anxiety: limbic-dorsal attention network (DAN) and default mode (DMN)-DAN. In line with several other infant MRI studies using this approach, we found that within both network pairs ROI-ROI associations with behavior were both positive and negative. Specifically, 62% of the significant ROI pairs within the limbic-DAN network and 67% of the ROI pairs within DMN-DAN network exhibited negative associations with maternal anxiety (See Figure 1). Moderation analyses demonstrated that ROI pairs exhibiting greater DMN-DAN rsFC were associated with heightened the association between BI and later anxiety (See Figure 2).

In summary, maternal anxiety is associated with alterations in infant limbic-DAN and DMN-DAN rsFC. Furthermore, BI infants who show higher rsFC between DMN-DAN are more likely to exhibit anxiety in early childhood. This work supports the theory that the infant brain is shaped by maternal behavior in ways that subsequently impact anxiety risk trajectories. Critically, this work is among the first to illustrate that the infant rsFC can inform longitudinal pathways to anxiety.

Symposium 6.4 - Pathways to early phonological development: integrating perception, memory, motor, and social systems

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Summary

This symposium explores how internal factors and the social environment jointly shape early phonological development. The first paper uses home video and audio recordings to show that French infants' attention to talking faces shifts across the first two years in relation to speech input and emerging vocal skills. The second paper introduces a method to assess infants' temporary storage of speech sequences, revealing early links between phonological working memory,



vocalizations, and caregiver input in Italian infants. The third paper examines sensorimotor influences on prosody perception in Portuguese infants, comparing typically developing infants and infants with Down syndrome. The final paper shows that robot-provided cues can hinder word segmentation in German infants. Together, these culturally diverse studies depict phonological development as a multisystem, context-dependent process and invite discussion on how different systems jointly contribute to early language learning.

Details

Abstract 1,

Where infants will look on a talking face: A longitudinal study in the first two years of life: Infants' attention to the mouth of a talking face increases with age, a trend thought to be linked to speech production, bilingualism, and/or unfamiliar language processing (Lewkowicz & Hansen-Tift, 2012; Pons et al., 2015; Tsang et al., 2018). This study examines mouth-looking in monolingual French-learning infants and is the first to evaluate correlations between mouth-looking and home recordings of caregiver speech input and infant vocalizations. Using a longitudinal design, 70 infants were tested at four timepoints (Time 1-4, corresponding to approximately 4, 8, 12, and 18–21 months), and viewed a bilingual speaker narrating a story in both French (a familiar language) and English (an unfamiliar language). Daylong LENA recordings and parental questionnaires at Times 1-3 provided measures of adult word counts (AWCs), infant vocalization counts (CVCs), and babbling complexity.

Results first established that infants showed increased mouth-looking over time ($p < .001$), but no overall effect of language familiarity ($p > .39$), contrasting with prior findings of increased mouth-looking to unfamiliar languages (Lewkowicz & Hansen-Tift, 2012; Birulés et al., 2019). Substantial individual variability was observed (Figure 1).

Second, mouth-looking across age was not predicted by quantities of adult speech input ($p > .75$) or child vocalizations ($p > .13$), but was marginally predicted by babbling complexity ($p = .058$; cf., Tsang et al., 2018). However, clearer quantity-based effects were found at Time 2 (~8 months; all p 's $< .005$; Figure 2). Infants hearing more adult speech looked significantly more at the French- than the English-speaking mouth compared to infants who heard less adult speech. Conversely, infants who vocalized more had the opposite pattern, looking significantly more at the English- versus French-speaking mouth. Thus, the quantity of speech input and infants' speech productions may influence visual attention to talking faces in dissociable ways, but only at specific developmental stages, and modulated by language knowledge.

Third, MCDI vocabulary outcomes were assessed at Times 3-4. At ~12 months (Time 3), overall greater mouth-looking to the French versus English-speaking face predicted higher receptive vocabulary scores ($p < .001$), even when controlling for speech input and production measures. No predictors were significantly associated with either receptive or productive vocabulary at Time 4 (18–21 months), possibly due to a reduced sample size.

With prior work (e.g., Morin-Lessard et al., 2019), these results challenge a simple understanding of U-shaped trajectories and language familiarity effects (Lewkowicz & Hansen-Tift, 2012; Hillairet de Boisferon et al., 2018). Instead, infant audiovisual speech processing is complex, shaped by interactions between age, linguistic environment (e.g., speech input quantity), and infants' own speech-motor development. Mouth-looking likely serves different functions across development, like supporting phonological acquisition in early stages and potentially later becoming more social (Pons et al., 2019). These insights contribute to a broader understanding of how infants integrate audiovisual cues in language learning and may inform future clinical work. For example, reduced



mouth-looking is observed in children with language impairments (Pons et al., 2018), and the present data suggest that several factors (speech input, production abilities, etc.) may modulate that link.

Abstract 2,

Bidirectional links between infant phonological working memory, vocalizations, and language input :

Phonological working memory (pWM) supports early speech processing, vocabulary acquisition, and later linguistic achievement (Baddeley, 2000; Gathercole & Baddeley, 1989; Vihman, 2022). In older children, the relation between pWM and language is bidirectional: pWM predicts vocabulary growth, and linguistic experience strengthens memory (Gathercole et al., 1992; Keren-Portnoy et al., 2010). Yet less is known about how pWM operates before age 3, despite infants' well-documented ability to retain speech information (Saffran, 2020; Kabdebon et al., 2019). The linguistic environment also plays a key role: higher adult word input, conversational turn-taking, and contingent responsiveness support infants' vocal practice and later language skills (Tamis-LeMonda et al., 2014; Gilkerson et al., 2018). Despite strong evidence for interactions among memory, vocal behavior, and language input in childhood, it remains unknown how and when these links emerge in infancy.

To better understand the early links among pWM, language development, and the linguistic environment, we tested 90 Italian infants aged 5-24 months. To assess pWM, we used a two-alternative looking paradigm consisting of rapid learning blocks that evaluated infants' ability to remember target sequences and predict upcoming events while distracting stimuli were intermixed. To measure memory span (MS), we varied the difficulty of the sequences to be remembered depending on each infant's performance. Each infant started with trisyllabic pseudowords and then moved to more difficult (quadrisyllabic) or easier (bisyllabic) sequences based on the accuracy of their first look at test trials. To examine how early pWM relates to language and the linguistic environment, we collected LENA-derived child vocalizations/min (CVC/min), adult words/min (AWC/min), conversational turns/min (CTC/min), and MB-CDI expressive, receptive, and gesture scores.

Infants showed a mean memory span of 2.21 (SD = 1.02). Ordinal logistic models showed that, among linguistic measures, CVC/min predicted memory span (OR = 2.16, $p = .007$); expressive vocabulary, receptive vocabulary, and gestures did not (all $p > .40$). A linear model confirmed the reverse direction, with memory span predicting CVC/min ($\beta = 0.21$, $p = .004$), revealing a reciprocal relation between early vocal motor activity and pWM. We then evaluated contributions of the language environment. CTC strongly predicted infants' vocalizations ($\beta = 0.23$, $p < .001$) but did not predict MS OR ≈ 1.48 , $p = .74$. AWC, however, moderated the relation between memory and vocalizations in both directions: the MS $\rightarrow$ CVC ($p = .008$) and CVC $\rightarrow$ MS ($p = .027$) associations were strongest for infants exposed to greater amounts of adult talk. We also examined whether environmental characteristics mediated links between MS and CVC/min. A single pathway emerged: infants with higher MS engaged in more conversational turns, which in turn predicted higher vocalization rates (indirect effect = 0.10, $p = .044$).

Together, these findings provide a first characterization of pWM in infancy and show that early pWM is embedded in a bidirectional, input-sensitive developmental system integrating memory capacity, vocal practice, and the linguistic environment.



Abstract 3, Sensorimotor influences on infant speech perception of prosody in typical and atypical development: Recent advances on the perception-production link in early development have shown that sensorimotor influences on infant auditory speech perception modulate phoneme discrimination, highlighting the integration of sensorimotor information and auditory speech prior to speech production. Although the perception of prosody is multimodal, sensorimotor influences on prosody perception have hardly been investigated. We examined sensorimotor influences beyond phoneme perception, by testing a stress contrast (trochaic vs. iambic stress), and an intonation contrast (statement vs. question intonation) in two populations of 6-month-olds: typically developing infants (TD), and infants with Down Syndrome (DS). DS is a genetic disorder commonly associated with oral-motor dysmorphologies known to impact speech production. To our knowledge, the effects of oral-motor dysmorphologies on infant speech perception have never been studied.

TD infants listened to the prosodic contrasts without and with temporary oral-motor impairments induced by two teething toys: a gummy teether and a flat teether. Infants with DS, who show long-term oral-motor impairments characteristic of their condition, also listened to the prosodic contrasts. Following Frota et al.'s (2014) study, a modified version of the visual habituation paradigm was used to test discrimination of the intonation contrast (I). To test perception of the stress contrast (S), the anticipatory eye movement paradigm implemented with eye-tracking was used following the methods in Frota et al. (2020). Three groups of TD infants (no object in the mouth, with gummy teether, and with flat teether) and one group of infants with DS performed I and S, with experiment order counterbalanced across participants. Sixty TD infants (20 per group) and 14 infants with DS for I and 16 for S were included in the current analysis.

TD infants discriminated the intonation contrast both in the absence of the teething toys and in the gummy teether condition, but not in the flat teether condition (Fig.1A). However, the stress contrast was discriminated only without a teether, while both teethers disrupted discrimination (Fig.1B).

Ultrasound imaging data collected for a sample of 10 TD infants showed significant differences in different parts of the tongue contours between the no object and flat teether conditions versus the no object and gummy teether conditions, with the flat teether impacting tongue position more broadly than the gummy teether (Fig.2). Infants with DS were able to successfully discriminate the intonation contrast (Fig.1C), but failed to discriminate the stress contrast (Fig.1D). The results from this clinical group suggest effects of oral-motor dysmorphologies on perception that approximate those temporarily induced by the gummy teether in TD infants. Ultrasound tongue imaging data for a sample of infants with DS is currently under analysis.

Our findings demonstrated that sensorimotor influences modulate speech perception beyond phoneme discrimination. Their effects on infants' perception of prosody were different for stress and intonation, pointing to specificities in the perception-production link with stress perception being more disrupted than the perception of intonation. These findings offer new insights into sensorimotor integration and the perception-production link in typical and atypical development.

Abstract 4, Robot-Provided Social Cues Show No Evidence of Enhancing Infant Word Segmentation: Infants develop the ability to segment words from speech during their first year of life. While much research has focused on acoustic cues, emerging evidence indicates that social cues can further facilitate this development (Vanoncini et al., 2022; 2024). One proposed explanation is that social cues enhance infants' attention to speech, thereby supporting learning (Szufnarowska et al., 2014; Csibra & György, 2009). Correlational work suggests an association between infants' attention to social cues and early word segmentation (Vanoncini et al., 2024), but when tested directly the evidence becomes less clear (Çetinçelik et al., 2024). Social robots such



as the Furhat (Al Moubayed et al., 2012) offer a promising tool for investigating this relationship, as they can consistently display social behaviors while maintaining experimental control. Therefore, we investigate whether infants process speech provided by a robot and whether robot-provided social cues enhance their attention and speech processing performance.

Specifically, we tested 32 German-learning infants aged 8 to 13 months. We used a classical speech segmentation paradigm (e.g., Jusczyk et al. 1999), modified such that a Furhat robot delivered the familiarization passages. Auditory stimuli were prerecorded by a native German speaker. Infants were randomly assigned to one of two familiarization conditions: in the social cue condition, infants first observed a scripted interaction between the Furhat and an experimenter, including gaze shifts, facial expressions, and gestures, and then the Furhat recited passages containing two target nonwords while maintaining “eye contact” with the infant. In the control condition, the Furhat recited the same passages and produced the corresponding lip movements, but didn’t display social behaviors and kept its gaze directed downward. Following familiarization, infants were tested for recognition of target versus novel nonwords in a Head Turn Preference Paradigm. Linear mixed-effects models revealed a marginal interaction between social cue condition and word type ($p = 0.09$). Results of a nested model indicated a marginal preference ($p = 0.08$) in the condition without social cues, with longer looking times to novel than to familiar words, but no preference ($p = 0.5$) in the condition with social cues. Pearson correlations revealed no relationship between attention to the robot during familiarization and speech segmentation performance.

We tentatively interpret these results of the control condition to suggest a feasibility of using social robots in language acquisition research, providing a promising foundation for future application. The finding that infants in the control condition outperformed infants in the social cue condition raises questions about the effectiveness and naturalness of the provided cues. One possibility is that the cues were not natural enough to be processed efficiently, leading to increased cognitive demands and

reduced resources for speech processing. The robot’s semi-humanoid form, with a human-like face but non-humanoid body, may also have created perceptual ambiguity, weakening the intended communicative signal. Together, these findings suggest that while social robots provide valuable opportunities for studying the social context of language development, with the current Furhat implementation it remains difficult to systematically investigate which aspects of social cues actually support learning.

Symposium 6.5 - Tracing the developmental origins of human self-awareness: brain, body, mind and mechanism

Victoria Southgate¹, Andrew Bremner², Markus Tuente³, Katarina Begus¹

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Summary

Developmental science has focused intently on how infants understand other individuals, yet very little work has investigated the developmental origins of an understanding of self. This symposium brings together four speakers investigating the origins of self-representation in self-specifying signals deriving from the body and brain, emphasizing new paradigms and methods (both



behavioural and physiological), with the aim of delivering a foundation for investigating the developmental mechanisms underlying the origins of self-awareness. We include studies of early abilities to sense and integrate bodily cues (including multisensory and interoceptive cues as well as interpersonal sensory cues), investigations into conceptual, meta-representational and reflective forms of self-awareness (e.g., error detection), and, critically, longitudinal projects investigating the relationship between early available brain and body signals and a later developing conceptual self-representation.

Details

Abstract 1:

Investigating the origins of the multisensory bodily self with virtual reality: BabyMIRAGE

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Introduction: Researchers disagree about whether bodily self-awareness is innate and available from birth or develops gradually in postnatal life. Tests of bodily self-awareness in younger infants typically present video footage of leg movements which either match their own (through a live video-feed) or appear with spatial and/or temporal incongruencies, finding that very young infants are sensitive to such multisensory contingencies. Yet such studies typically present visual cues to the infant's body on screens out of bodily space (and well beyond the tolerance for visual embodiment in adults), and so infants' responses likely reflect representations of contingencies between body movements external events. Here we pioneered an infant virtual reality platform (BabyMIRAGE) which presents infants with virtual (and manipulable) images of their own legs within bodily space.

Hypotheses: We examined whether 4-month-old infants would demonstrate preferences for VR images of their legs moving either in synchrony or out of synchrony with their own movements, under two conditions: i) where their limbs were presented in the real size, and ii) where their limbs were scaled up to appear larger than their real size. Given previous findings across infants and adults (e.g., Morgan and Rochat, 1997; Tsakiris & Haggard, 2005), we predicted that a preference for synchronous movements would disappear when visual featural cues to their limbs were atypical (i.e., in the large condition).

Study population: Twenty-one 4-month-old infant participants took part in this study ($M = 129$ days, $SD = 12.0$ days) – a further 8 participants were excluded due to infant fussiness ($n = 4$) or experimenter error ($n = 4$). Prior to data collection a minimum sample size of 21 was established using an a priori power analysis in order to detect a medium-large effect ($d_z = 0.65$) with an alpha level of .05 and power of .80. Infants were recruited from a database of participants of mixed but predominantly Caucasian ethnicity.



Methods: Infants were presented with Large and Regular limb size trials in BabyMIRAGE, in alternating sequence (up to a maximum of 8 trials; Fig. 1). In each trial the experimenter engaged infants in a leg bouncing game with, holding their feet and moving them up and down. Using video manipulation in BabyMIRAGE, on each trial one of the leg's movements were shown in synchrony whilst the other's movements were shown delayed by 246 ms. Visual preferences for the synchronously moving leg were recorded as a proportion of total looking at synchronous and asynchronous legs.

Results: Proportion preferences for the synchronously moving limb showed no reliable difference from chance (0.5) across both Large and Regular limb size conditions (Fig. 1). However, the large spread of synchrony/asynchrony preferences across the group were driven by individual preferences which were consistent between Regular and Large limb conditions, demonstrating that 4-month-olds are sensitive to visual-prioriceptive contingencies in their own leg movements. Contrary to previous findings and to our hypothesis, this sensitivity to visual proprioceptive contingencies was present independently of substantial differences in visual size cues to the infant's own limbs.

Abstract 2

From metacognition at 12 months to self-representation at 18 months

Katarina Begus & Cécile Gal

Introduction: Adult human cognition is characterised by remarkable capacities for self-reflection. Yet, despite its centrality to human cognition, the mechanisms of how our mind reflects upon itself remain subject of much theoretical debate. Developmental work concerning self-related processes has largely focused on the bodily-self (Filippetti et al., 2014), and the role of social interactions in scaffolding the developing self representation (Gergely & Watson, 1996; Southgate, 2024). While interoceptive bodily signals may be the earliest available in development, a mature conceptual self-representation critically includes not only bodily, but cognitive components. Recent research evidenced behaviours as well as neural correlates consistent with the presence of cognitive self-monitoring capacities in infants (Goupil & Kouider, 2016), before they evidence conceptual self-representation. Therefore, another route to investigating the building blocks of our reflective minds is to look for precursors to conceptual self-representation in infants' capacities of cognitive self-monitoring.

Methods & Study Population: In this longitudinal study, infants (N=58) first took part in an infant-controlled, memory-based, decision-making task at 12 months. Using gaze-responsive eyetracking and concurrent EEG recordings, infants interacted with a display, and actively gathered information and made decisions. In each trial, infants had to select cards with matching images by gazing at them. Crucially, there was a 500ms delay between infants' gaze landing on a chosen card and the presentation of the visual feedback informing them whether their choice was correct. This allowed for measuring infants' internal error monitoring (reflected in error-related negativity, ERN) prior to feedback. To investigate whether this early capacity of error-monitoring predicts the later emergence of self-representation, the same infants were tested again 6 months later, using the MSR task.



Hypothesis: We hypothesised that internal error monitoring constitutes a building block of the developing conceptual self-representation and will therefore developmentally predict its emergence.

Results: The results revealed a difference in infants' neural activity following incorrect as compared to correct choices (ERN: 33-172ms post-choice ($p = 0.013$)), indicating infants' capacity to internally monitor their own decisions (before receiving external feedback). Moreover, the magnitude of the ERN at 12 months of age was found to correctly predict which infants will exhibit evidence of self-representation 6 months later ($p = 0.031$; 90.9% of mirror self-recognisers classified correctly). This relationship was specific to internal error-monitoring and not to external feedback processing, and could not be explained by infants' age or general cognitive development. Moreover, when directly comparing infants, who later exhibited self-representation, to those, who did not, we found that only self-recognisers exhibited the ERN effect, and adjusted their behaviour following errors (post-error increase in exploration and slowing of decision making), whereas non-recognisers did not.

The fact that internal error-monitoring not only operates before the emergence of self-representation but also developmentally predicts its emergence, suggests that explicit self-awareness may at least in part be rooted in simpler and developmentally earlier cognitive-monitoring mechanisms that enable infants to track their own cognitive activities and which, over time, could become integrated into a richer conceptual understanding of the self as an epistemic agent.

Abstract 3

Title: From bodily signals to prosocial behavior: interoceptive sensitivity and empathic concern at 9 and 18 months

Authors: Markus R. Tünte¹, Laura Neumann¹, Gesine Jordan¹, Rebecca Lutz¹, Ezgi Kayhan², Manos Tsakiris³, Stefanie Hoehl¹

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Introduction: Theoretical models emphasize that interoception, the perception of bodily signals such as heartbeat or breathing, is important for early social development. Interoceptive signals are central to early interactions, as infants cannot regulate their needs by themselves and rely on appropriate responses of their caregivers. Furthermore, research with adults shows that interoception plays an important role in the differentiation between self and others (Palmer & Tsakiris, 2017). However, there are no empirical findings on whether associations between interoception and social cognition can already be observed in the first two years of life, a key period for social cognitive development.

Methods & Study Population: The present study aims to fill this gap in the literature by examining 9 month old ($N = 90$) and 18 month old ($N = 54$) infants in a longitudinal design. Infant interoceptive sensitivity was measured with two gaze contingent preferential looking paradigms in which stimuli were presented synchronously or asynchronously with breathing or heartbeat. Infant empathic concern was measured by replicating a paradigm in which the primary caregiver simulated being in



pain for one minute. The child's behavior was macro coded at both time points replicating an existing coding scheme (self distress, inquiry behavior, concerned affect, prosocial behavior). In addition, we micro-coded the behavior of the 18-month olds by adapting the existing coding scheme to indicate, for every frame, whether a given behavior was present.

Hypothesis: We hypothesized that behaviors related to self-other distinction (prosocial behavior, inquiry behavior, concerned affect) would show a positive association with infant interoception as stronger bodily signals may help infants distinguish themselves from others. In turn, behaviors related to self-other blurring (self-distress) would show a negative association with infant interoception as reduced perception of one's own bodily signals could lead to greater self-other blurring.

Results: In our preregistered correlational analysis, we found a significant association between prosocial behavior and cardiac interoceptive sensitivity at 18 months ($r = .46$, $p = .015$), but not with other behaviors or at 9 months. However, macro level coding aggregates behavior over long intervals, which can obscure brief and subtle expressions of prosocial responding. Therefore, we repeated the analysis with the micro-coded data for prosocial behavior at 18 months using mixed-effects logistic time series models that estimate the probability of a behavior being present in every frame. Using this approach we were able to replicate the positive relationship between infant cardiac interoception and prosocial behavior at 18-months ($p = .010$).

Our findings show an association between interoception and social cognition in early childhood, but only in specific behavioral domains and in the 18 month old sample. This pattern might suggest that at 18 months, the interoceptive and social cognitive systems are sufficiently developed for this relationship to manifest in behavior. In addition, the analysis using the micro-coding data replicated this association, indicating a promising avenue for future research. Given that interoception plays an important role in social cognition and related (sub)clinical psychopathologies, our results provide an empirical basis for its relevance in the first years of life.

Abstract 4:

Investigating the role of caregiver-infant interpersonal synchrony in the development of a self-representation.

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Introduction: Extensive research suggests that interpersonal synchrony (IPS), the time-locked coordination of changes in signals between interacting people, blurs the boundary we perceive between self and other (Semin & Smith, 2008). Developmental data suggest that infants raised in cultures with higher levels of maternal imitation, implying time-lagged synchrony, pass the mirror self-recognition (MSR) test earlier than infants raised in cultures with higher levels of synchronous imitation and thus greater experience of simultaneous IPS (Cebioglu & Broesch, 2021). These findings suggest infants' experience of IPS as an important factor in the development of self-awareness.



Hypotheses: We tested the idea that synchronous interactions lead to increased self–other blurring, delaying the emergence of distinct self-representation. Thus, the current study tested the hypothesis that greater IPS is associated with later onset of MSR and that infants who experience more IPS will pass the MSR test later than infants who experience less IPS.

Study population and methods: A cohort of 120 Danish infants were recruited. To measure IPS, 12-month-old infants and their mothers wore accelerometer sensors on their dominant arm and leg during a free play session in the lab, and for the following 8 days at home. This provided continuous data on the movement dynamics between caregivers and their infants. Experience sampling was used to get caregivers' reports on what they and their infant were doing at different time points and this was used to constrain the periods of analysis. To distinguish between simultaneous movement synchrony and time-lagged synchrony, IPS was measured using windowed cross-correlation and wavelet coherence in the periods of reported interactions, for a narrow (lag: ± 1 second) and wide (lag: ± 10 seconds) window. At 18 months, infants participated in the MSR test. Infants also provided data on inhibitory control, intended to be a domain-general measurement of cognitive development for which we did not predict any association with IPS.

Results: 74 infants contributed both valid accelerometer data and MSR data (37 mirror recognisers, 37 mirror non-recognisers). Contrary to our initial hypothesis, mother-infant dyads who exhibited greater interpersonal synchrony during naturalistic interactions at home, had infants who passed the mirror self-recognition test earlier than those who were part of dyads exhibiting less IPS, regardless of the lag window used (± 1 second: $t(73) = -2.36, p = 0.008$; ± 10 seconds: $t(73) = -2.82, p = 0.004$). There was no difference in performance between mirror recognisers and non-recognisers on the inhibitory control task based on an accuracy difference score between prepotent and inhibition trials ($t(60.69) = -0.52, p = 0.60$, Welch's test). While the direction of the relationship is contrary to our initial hypothesis, we discuss the data in relation to the presence of potential lag between mother-infant movement and to what extent these dynamics might better fit the time-lagged synchrony inherent in maternal imitation, which predicts earlier MSR in cross-cultural samples.

Symposium 7.1 - Biobehavioral co-regulation in early development: caregiving pathways to infant health

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Summary

Caregiver–infant co-regulation shapes infants' physiological and behavioral outcomes. This symposium integrates international meta-analytic, naturalistic, longitudinal, and RCT evidence on how sensitive caregiving calibrates regulatory systems and downstream health. *Meta-analytic evidence* indicates that attachment security is associated with adaptive physiological stress responses. *Naturalistic evidence* shows that maternal vocalizations and sensitivity modulate infant autonomic arousal and scaffold infant signaling. *Longitudinal findings* demonstrate that maternal sensitivity predicts greater infant autonomic regulation, which in turn predicts lower risk of obesity



in toddlerhood. *RCT evidence* shows that an early 5-week skin-to-skin intervention in full-term infants reduces early crying and internalizing symptoms in middle childhood. Together, these convergent findings reveal that early sensitive caregiving calibrates infants' regulatory physiology with lasting implications for health.

Details

Abstract 1, Title: Meta-analytic evidence of physiological stress calibration by child-parent attachment security

Background. Early childhood is a sensitive window for calibrating children's physiological stress-regulation systems, which depend on the coordination between internal biological mechanisms and external caregiver regulation. Sensitive caregiving and secure attachment are theorized to scaffold children's developing stress-response systems, yet empirical findings are mixed, particularly beyond the narrow context of caregiver separation–reunion paradigms and categorical attachment classifications. Due to these limitations, to date, we lack a comprehensive synthesis of the sympathetic (SNS) and parasympathetic (PNS) autonomic systems and the hypothalamic-pituitary-adrenal (HPA) axis calibration in relation to the quality of early attachment relationships.

Methods. This preregistered meta-analysis synthesized studies examining associations between attachment to a primary caregiver and physiological responses to standardized stressors. Studies were included if they assessed infant-parent attachment (continuous or categorical) and measured SNS, PNS, or HPA axis activation. Effect sizes (r) were transformed to Fisher's z and direction-adjusted (r_{adj}) so that positive values reflected more adaptive physiological regulation. Random-effects models (DerSimonian–Laird) were conducted separately for each physiological system. Planned moderator tests (e.g., stressor type, physiological feature, sample type, attachment assessment) will be presented at the conference.

Results. The meta-analytic dataset comprised $N=45$ studies and $k=105$ effect sizes (of which: $k=32$ unspecified; $k=26$ different attachment classification) (Table 1), representing 10440 children ($M_{age}=26.68m$). Results revealed that children with more secure attachment exhibited greater PNS regulation during stress, as reflected in a small-to-moderate association between attachment security and vagal functioning ($r_{adj}=.20$, 95% CI [.05, .35], $k=11$). This pattern, commonly indexed through measures such as respiratory sinus arrhythmia or heart rate variability, suggests that securely attached children engage physiological mechanisms that support effective calming and regulatory flexibility in challenging contexts. Attachment security was associated with reduced SNS arousal [$(r_{adj}=-.52$, 95% CI [-.69, -.30], $k=13$)], indicating that securely attached children show markedly lower activation of stress-related mobilization systems (e.g., electrodermal activity, heart-rate acceleration, or pre-ejection period) when confronted with stressors. In addition, attachment security predicted lower HPA-axis activation, evidenced by a small but significant association with cortisol responses ($r_{adj}=-.15$, 95% CI [-.24, -.05], $k=23$), suggesting that secure attachment is linked to reduced hormonal stress reactivity. Effect sizes are illustrated in the Forest Plot (Figure 1). Across all systems, heterogeneity I^2 values ranged from 76% to 86%, indicating that effect sizes varied widely by study-level characteristics. Potential publication bias was observed, particularly among smaller studies, suggesting that non-significant findings may be underrepresented in the literature.



Discussion. Attachment security contributes to children's bioregulatory functioning in distinct ways, depending on the stress system. Securely attached children showed physiological profiles characterized by greater parasympathetic engagement during stress, reduced sympathetic mobilization, and attenuated HPA-axis activation. This constellation of effects reflects more adaptive stress regulation and less arousal during stress than that in children with lower attachment security. Further, these preliminary findings underscore the need to move beyond studying isolated physiological systems toward integrative, multisystem models of stress regulation. Future synthesis efforts should incorporate analytic strategies that capture cross-system coupling rather than examining each system in isolation.

Abstract 2, Title: Does the content of maternal vocalisations have co-regulatory benefits?

Measures of maternal behavioural and affective contingency and flexibility/attunement predict adaptive co-regulation (Lobo & Lunkenheimer, 2020), but little is known about the in-the-moment mechanistic processes underpinning this. We aimed to examine the content of maternal vocal display across the day and identify which types had immediate effects on infant autonomic signalling; and on infant vocal signalling.

We hypothesised that (a) different types of maternal vocalisations would have either a neutral, dampening, or excitatory effect on in-the-moment infant autonomic signalling (heart rate); (b) maternal affect and intensity would moderate this effect; (c) the matching of maternal and infant affective display would predict infant vocal signalling.

We used miniaturised 'wearable' recording devices on a typically developing population of 31 5-15-month-old infants and their mothers in London, UK. We gathered day-long at home ECG and microphone data. Voiced audio segments were extracted automatically (Lavechin) and hand-coded for affect (positive, neutral, negative), intensity (low, medium, high), and type of vocalisation for mum and infant. Speech segments were matched to maternal and infant ECG; and magnitude of infant heart rate change in the time period following each vocalisation compared to prior was analysed.

Hierarchical linear mixed effects ($n=31$) show most maternal vocalisation types had either a dampening or neutral effect on infant arousal immediately following the vocalisation when moderated by vocal intensity. Redirective/imperative and infant-directed maternal mind-minded (i_MMM) vocalisations significantly predicted increased infant arousal change in the two minutes following the vocalisation ($p<.001$; $\beta=-0.07$, $p<.0001$) when not in interaction with intensity. Maternal vocal intensity significantly moderated the effect of vocalisation type. Low and high intensity in interaction with i_MMM (low: $\beta=-0.14$, $p<.001$; high: $\beta=-0.18$, $p=0.014$) significantly predicted decreased infant arousal changes. Low intensity redirective/imperative vocalisations significantly predicted a decreased infant arousal change at all arousal ($\beta=-0.16$, $p<0.01$); and at elevated infant arousal ($>80^{\text{th}}$ percentile) ($\beta=-0.14$, $p<0.01$); however, high intensity redirective/imperative predicted increased infant arousal change at elevated infant arousal, although this was not significant.

Maternal exact matching of infant vocal affect predicted fewer infant high intensity vocalisations ($\beta = -1659.31$, $p = 0.018$); this effect was moderated by age ($\beta = +143.87$, $p = 0.010$), indicating that



maternal exact affect matching more strongly predicted fewer infant high intensity vocalisations at older ages. Maternal exact matching of infant vocal intensity predicted greater infant low intensity vocalisations ($\beta = +2611.32$, $p = 0.044$); this effect as moderated by age (Age interaction: $\beta = -249.11$, $p = 0.012$). Specifically, maternal exact affect matching less strongly predicted greater infant low-intensity vocalisations at older ages.

In conclusion, specific maternal vocalisation types have a dampening or excitatory effect on in-the-moment infant arousal changes when in interaction with maternal vocal intensity. Maternal vocal matching of infant affect and intensity predicts infant use of vocal intensity over time. Taken together, these findings suggest an immediate co-regulatory effect and a longitudinal vocal communicative effect of type and affect/intensity of maternal vocal display.

Abstract 3, Title: Maternal Sensitivity During Feeding Predicts Lower Toddler Obesity Risk via Infant Physiological Regulation

Childhood obesity is a global epidemic, with 42 million children under age 5 having excessive adiposity. Given difficulty in reversing obesity once established, attention has shifted to identifying early life predictors of obesity to inform prevention efforts. Infant rapid weight gain is a robust predictor of subsequent obesity. Our goal was to identify moderators of this path and factors that promote healthy weight status. As detailed in a published protocol paper, we hypothesized that lower obesogenic feeding practices, higher maternal sensitivity, and higher infant emotion regulation, assessed when children were 1 and 2 years old, would (1) predict lower obesity risk as main effects and (2) reduce the strength of the association between infant weight gain from birth to 6 months and obesity risk at 2 years (i.e., moderating effects).

Pregnant individuals (299; 47% non-White; 42% primiparous) and their infants (49% female) from the USA participated. Mothers reported infant birthweight and length via phone, and infants were measured and weighed during the 6-month laboratory visit. Infant weight gain was calculated as the difference between WHO weight-or-length z-scores at 6 months and birth. Maternal obesogenic feeding practices were a summed index of 13 mother-reported feeding practices known to confer risk for childhood obesity. Maternal sensitivity was a latent factor derived from behavioral ratings during free play, distress eliciting tasks, and a feeding episode at both 1 and 2 years. Infant attention regulation and behavioral/emotion regulation were rated at 1 year during standard laboratory tasks and infant respiratory sinus arrhythmia (RSA) was scored during a non-stressful baseline and a series of distress eliciting tasks at age 1 using the Porges' method. RSA withdrawal from baseline to task was calculated; higher scores indicate better physiological regulation. The emotion regulation indicators did not load on a single latent variable and were maintained as 3 manifest variables. Toddler obesity risk was a latent variable composed of BMI-for-age, waist circumference to height ratio (i.e., central adiposity), and percent body fat derived from the Bodpod (i.e., total adiposity).

Data were analyzed using MPLUS with missing data handled via full information maximum likelihood. Infant birth weight and mother-reported child physical activity were specified as covariates (Figure 1). Consistent with prediction, higher infant weight gain from birth to 6 months predicted higher obesity risk at age 2. Because none of the proposed moderating effects were statistically significant, they were removed. Infant RSA withdrawal was the only variable that



promoted healthier outcomes, such that infants with better physiological regulation at age 1 had lower obesity risk at age 2. A post-hoc addition to the model demonstrated that maternal sensitivity observed during feeding at 2 months predicted better RSA regulation at 1 year and had an indirect effect on obesity risk at age 2.

In conclusion, early sensitive caregiving during feeding, a task often characterized by close physical proximity and skin-to-skin contact, promotes better infant regulation, which supports healthier weight outcomes. Thus, maternal sensitivity has critical implications for obesity prevention via its effect on the development of early regulatory capacities.

Abstract 4, Title: Effects of mother-infant skin-to-skin contact on childhood development: a Randomized Controlled Trial

Introduction: Parent-infant skin-to-skin contact (SSC) early in life is a simple intervention of proven benefit for the short- and long-term development of children. Preterm infants receiving SSC shortly after birth have better cardiorespiratory and thermal regulation, faster weight gain, enhanced cognitive development and executive functioning, and fewer behavioral problems. Benefits in full-term infants are faster weight gain, improved sleep, and cardiovascular stability. However, research on the benefits of SSC in children born full-term is scarce and often limited to the first weeks after birth. A Randomized Controlled Trial (RCT) on daily SSC after a full-term pregnancy found fewer internalizing and externalizing behavioral problems at 3 years in children receiving SSC compared to care-as-usual (CAU). In the current follow-up, preregistered, study on the same cohort, we investigated the effects of daily SSC in the first weeks after birth on child behavior, executive functioning, and sleep at 6 years of age.

Hypotheses: Based on the preterm literature and scarce full-term studies, we hypothesize that children receiving SSC will have fewer internalizing and externalizing behavioral problems, improved executive functioning, and fewer sleeping problems compared to children receiving CAU. In addition, we will perform an exploratory analysis to determine whether SSC is associated with prosocial behavior at age 6.

Study population: The SKIPPY study is an RCT including 116 pregnant women who were randomly allocated to the SSC (n=56) or CAU (n=60) group. The treatment group was instructed to perform one daily hour of SSC in the first five weeks postpartum. Participants from both groups kept a daily physical contact logbook from week 0-5, and filled in multiple questionnaires on child health and development during the study period, and at one, three, and six years after birth.

Methods: The 6-year-olds' behavior, executive functioning, and sleeping habits were reported by the mother through standardized questionnaires. Mann-Whitney U test and permutational multivariate analysis of variance (PERMANOVA) were used to compare the two groups using an intention-to-treat (ITT) and per protocol (PP) approaches. In addition, Pearson or Spearman's rank correlation was used to test dose-response effects within the SSC group.

Results: Fewer internalizing problems were found in the SCC group compared to care-as-usual in both the ITT and PP approaches. A weak effect in the same direction was found for externalizing



problems. Prosocial behavior, executive functioning, and sleep scores were not significantly different between the SSC and CAU groups.

Conclusion: This study showed that daily SSC can reduce internalizing behavioral problems up to six years after birth, thereby replicating the findings at three years. SSC reduced externalizing behavior at three years of age, but this effect was only weakly present at six years. This discrepancy might be due to the development of externalizing behavior over time and the influence of socialization in schools. Future replication research is needed, but to date, SSC appears to be a low-cost and easy-to-implement practice with beneficial behavioral effects in full-term infants.

Symposium 7.2 - From lab rooms to living rooms: The physical environment shapes infant behavior

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Summary

Infants develop in a physical environment. Researchers who study development in context apply a rich variety of methods. This symposium features four studies that leverage innovative methods to measure physical characteristics of the environment and their effects on infant behavior.

Presentation 1 uses home video tours and a custom annotation program to characterize toy availability and relations to object play in three cultures. **Presentation 2** collects 5-cm accurate, 3D digital replicas of infants' homes and tests how differences in home layouts shape walking.

Presentation 3 compares four environments (including a 'home-in-lab' space) to assess how activity context influences joint attention. Finally, **Presentation 4** uses home inventories and eye tracking to test if differences in physical stimulation moderate longitudinal associations between attention and self-regulation. Collectively, we highlight the importance of studying infants in context—and showcase methods for doing so.

Details

Abstract 1: Using video to capture infants' physical home environments and play with objects

Features of the physical home environment—especially object availability—shape infants' everyday play. Parents are key agents in organizing the home: They decide which objects are available and whether to store them in reach or out of sight. Thus, observations of the physical home environment provide a unique window into parents' socialization goals (e.g., piles of books may signal an emphasis on early literacy just as towers of blocks may signal an emphasis on spatial skills). Indeed, the physical environment is a core component of the cultural 'developmental niche' (Super & Harkness, 1986), and children's interactions with toys and other objects are fundamental to learning. Yet most research on toys report the presence (or absence) of objects from predetermined checklists, limiting identification of individual and cultural variation in toy quantity and types and how such variation shapes infants' everyday play.



In a sample of matched families from Seoul ($n = 21$), Hong Kong (HK; $n = 21$), and New York City (NYC; $n = 21$), we conducted video tours of infants' homes and 1-hour video-recordings of infants and mothers during everyday activity ($N = 63$; $M = 16.1$ months, $SD = 3.5$). Using a custom MATLAB annotation program and Datavyu (Figure 1A), we identified, quantified, and categorized each toy by type (e.g., books, blocks, digital toys) and accessibility (e.g., in or out of storage). We tested whether overall toy quantity, type, and accessibility related to the frequency and duration of toy play.

Across families, we identified 11,674 toys, with large individual differences in the number, types, and accessibility of toys (Figure 1B). Seoul homes had the most toys ($Mdn = 238$; $range = 43-908$), then HK ($Mdn = 149$; $range = 31-661$), and NYC ($Mdn = 147$; $range = 43-368$). Number of toys related to infant age, siblings, apartment size, and parent education, $\beta s = .12-.42$, $ps < .05$. Homes in Seoul and HK contained a larger proportion of language-related toys (e.g., books, alphabet posters) than homes in NYC, $\beta s = .10-.34$, $ps < .05$.

Preliminary data from natural observations ($n = 29$) yielded $M = 83.2$ bouts of infant object play ($Mdn = 15$ sec, $range = 3-510$). Infants spent $M = 71\%$ of their object interaction time manipulating toys, $M = 19\%$ with household objects, and $M = 10\%$ with food. The sheer number of available toys did not relate to the frequency or duration of infants' toy play bouts. However, infants played more frequently with toy types that were more abundant and accessible, $rs > .33$, $ps < .05$. Moreover, certain types of toys (e.g., mechanical, wind-up cars or a box of crayons) afforded sustained engagement independent of their quantity in the home (Figure 2).

Video-based annotations of the home environment offer valuable insights into how physical features shape infant object interactions across cultural communities. Infants engage more frequently with accessible and abundant toys—reflecting parents' organization of the environment—however, the duration of infants' interactions varies by the affordances of toys rather than sheer quantity.

Abstract 2: No space? No problem: Infants walk regardless of available space at home

Learning to walk is challenging. Infants must learn to keep balance in an upright posture, start and stop walking at will, produce sequences of steps in every direction, and navigate obstacles. The layout and contents of infants' home environments present natural opportunities to string steps together and natural challenges for navigating obstacles. Large furnishings typically remain fixed in space, creating stable and predictable layouts. But the locations of smaller, movable objects can change and result in a continually shifting landscape. Here, we tested relations between the layout and contents of infants' homes and the quantity and characteristics of infant walking.

We visited 14.5-month-old walking infants (preliminary results from 29 of 52 infants) at home and videorecorded 1 hour of everyday activity. From video, we identified where infants spent time (e.g., kitchen, living room) and how (e.g., path shape) and how much (e.g., number of bouts, time walking) infants walked. We used Matterport technology (a tool designed for realtors) to create 5-cm accurate, 3D digital renderings of infants' homes and 2D blueprints of layouts and dimensions



of each room (Figure 1A-B). From Matterport, we calculated the total area of each home and open versus occupied floor space.

Homes ranged from 21 m² to 129 m² ($M = 61$ m²; Figure 2A) and open floor space from 9 m² to 75 m² ($M = 33$ m²; Figure 2B). All homes had floor space occupied by large, stationary furnishings ($M = 30\%$, $SD = 6$; Figure 2C) and small, movable objects ($M = 7\%$, $SD = 3$; Figure 2D). Larger rooms had more floor space covered by furnishings and objects, $r_s > .65$, $p_s < .001$, suggesting that contents were dispersed when space was available. Although homes had $M = 6$ rooms ($range = 3$ to 10), infants spent most time in $M = 4$ rooms ($range = 1$ to 6); living room, kitchen, baby bedroom, and hallways were most popular. Infants initiated $M = 234$ walking bouts/hour ($SD = 95$) and walked for $M = 14$ min/hour ($SD = 9$). Half of infants' bouts contained at least one non-forward step ($M = 53\%$, $SD = 16$) and most followed curved paths ($M = 68\%$, $SD = 15$). However, to our surprise, preliminary results (based only on rooms where infants spent time) showed no significant relations between home layouts and any measure of infant walking, $p_s > .05$.

Why? We hypothesize that infants capitalize on the space available by producing different types of walking regardless of the constraints of their environment. In ongoing analyses, we are mapping bout-level connections between walking and the environment in real time. For example, infants may produce short bouts or take steps in place when rooms are tight and cluttered, long straight paths in open spaces, curved paths around obstacles, or retrace their steps when necessary. Thus, although the general layout of home environments do not appear to shape total quantities of walking, the features of the home layout may shape how walking unfolds in the moment.

Abstract 3: Generalizable natural behavior across diverse contexts: A multi-environment study of joint attention

A central goal of developmental science is to produce empirical findings that are reproducible and generalizable beyond the specific circumstances of a single study. Yet many paradigms rely on structured laboratory tasks that may not reflect the complexity and variability of everyday interactions (Fausey et al., 2016). The present work examines whether core findings about joint attention (JA)—a construct foundational to early learning (Carpenter et al., 1998)—generalize across nine studies that differed in their physical environments, task structures, and behavioral demands. Our goal was not to test whether environments produce identical behavior, but whether the structure of JA remains stable across diverse real-world contexts.

The first six datasets were collected in a stripped-down laboratory space where all surfaces were white and dyads sat across from each other at a table (Figure 1A). These studies were longitudinal, following infants from 9 to 24 months, and were designed to assess whether JA patterns observed early in development generalize across age. The next two datasets provided an environmental comparison: one took place in a more naturalistic playroom containing many toys, and the other was collected in infants' homes during free play (Figure 1B-C). The final dataset tested generalization to everyday activity, as parents prepared a snack while children sat across from them—a common and ecologically meaningful context—in a lab designed to look like an apartment (Figure 1D).



Across all datasets, parent–infant dyads wore head-mounted eye trackers that continuously captured moment-to-moment gaze. Coders annotated infants’ and parents’ manual actions. This multimodal dataset enabled us to test the generalizability of three robust findings from prior lab-based work: (1) parents look at infants’ faces more than infants look at parents’ (Yu & Smith, 2013), (2) both infants and parents lead and follow one another into JA (Yu & Smith, 2017), and (3) dyads use multiple real-time pathways—gaze following, hand following—to establish and sustain joint attention (Yu & Smith, 2017).

Across all studies, a consistent pattern emerged: the micro-level details of behavior varied across environments, but the macro-level structure of JA was remarkably stable. For example, face looking was highest in the stripped-down lab, likely because dyads were oriented face-to-face. Children in these minimalist settings also led more JA bouts, whereas in the playroom, at-home sessions, and meal-preparation context—with 24+ objects and richer activity—leadership was more evenly shared. The specific pathways used to establish JA also shifted: object-rich environments favored hand-following, whereas sparse contexts elicited more gaze following (Figure 2).

Despite these contextual shifts, the overall prevalence of face looking, the bidirectionality of leading and following, and the multi-pathway nature of JA were consistent across all datasets. These findings reveal a dynamic interplay between environment and behavior: settings shape the form that behaviors take, but dyads are flexible and equipped with multiple coordination pathways. When one pathway is constrained, dyads adapt by relying on others, preserving the underlying structure of coordinated attention. Together, this work demonstrates that high-resolution, naturalistic measurement provides a powerful lens for directly assessing generalizability.

Abstract 4: Environmental Tuning of Infant Attention to the Home Sensory Ecology Reveals Distinct Pathways to Self-Regulation

Rationale: Infant attention is a key component of early self-regulation development, yet the contextual factors that shape these associations remain unclear. Drawing on an adaptive calibration perspective, we tested whether the predictive value of early attention varies with the sensory ecology of the home environment. Across two longitudinal cohorts of geographically and sociodemographically diverse infants, we used remote eye-tracking to measure infants’ peak look durations and examined whether home sensory stimulation (e.g., noise, visual clutter) moderated associations between attention patterns and later self-regulation abilities.

Method: In Study 1, infants aged 3–13 months (N = 114; 5% Asian, 10% Black, 13% Multiracial/Other; 21% Hispanic/Latine, 51% White) completed a free-viewing visual attention task previously validated in both lab (Blankenship et al., 2019; Kraybill et al., 2019) and remote studies (Werchan et al., 2024, 2025; Werchan, Thomason, et al., 2022). Home sensory stimulation was evaluated using the Confusion, Hubbub, and Order Scale (CHAOS; Matheny et al., 1995). Self-regulation was assessed at 24 months via parent-report measures of child effortful control, using the Early Child Behavior Questionnaire (ECBQ; Putnam et al., 2006) and measures of child behavioral dysregulation, using the Strengths & Difficulties Questionnaire (SDQ; Goodman, 1997).



In Study 2, we used the same methods to test a second independent sample of infants ($N = 148$; 4% Asian, 9% Black, 18% Multiracial/Other; 24% Hispanic/Latine, 45% White), measuring attention at 4-months followed by effortful control at 12 months.

Results: In Study 1, we found that home sensory stimulation moderated associations between infant attention and subsequent behavioral dysregulation, $\beta = -0.23$, $p = .010$, and effortful control scores, $\beta = 0.22$, $p = .020$. Specifically, we found that shorter look durations across the first year predicted better self-regulation in low-stimulation homes but worse self-regulation in high-stimulation homes (Figure 1). In Study 2, we again observed a significant interaction between home sensory stimulation and 4-month-old attention on 12-month effortful control scores, $\beta = 0.23$, $p = .011$. Replicating Study 1 findings, we again found that shorter look durations predicted higher effortful control in low-stimulation homes, but the opposite pattern emerged in high-stimulation homes (Figure 2).

Conclusion: These findings reveal an environmentally contingent pathway of self-regulation development. Rather than reflecting fixed traits, our findings indicate that early attentional patterns appear to gain meaning through their fit with the demands of the surrounding environment. Taken together, this work suggests that developmental patterns that are adaptive within specific ecologies may appear maladaptive when removed from their original context, underscoring the need for context-sensitive approaches in understanding self-regulation.

Symposium 7.3 - Early cortical tracking of speech: relations to language development and neural maturation

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Summary

The symposium presents three complementary perspectives on how early neural dynamics support infants' emerging language abilities. All contributions examine speech-brain coherence (SBC) early in life but differ in developmental focus, populations, and analytic approaches. Study I presents longitudinal EEG evidence from monolingual infants, showing that syllable-rate tracking decreases from 6 to 12 months and does not predict later vocabulary. Study II extends this question to mono- and bilingual infants, demonstrating stable cortical tracking across 4 and 7 months and language environments, but again no reliable links with later vocabulary. Study III tests whether neural maturation (EEG aperiodic slope) relates to concurrent SBC. More mature neural profiles show stronger phoneme-rate tracking, highlighting a link between maturation and speech processing. Together, these studies clarify to what extent SBC reflects variation in early speech and language development.

Details

Abstract 1

Title: Neural tracking and language development in early life: A longitudinal approach



One of the most fascinating recent discoveries in neurolinguistics is that neuronal oscillations synchronize with external signals like speech (Giraud & Poeppel, 2012). This mechanism is believed to show enhanced attentional focus between interlocutors, as well as to play a role in segmenting continuous speech into smaller linguistic units (Menn et al., 2022). Studies on infants show that infant-directed speech amplitude modulations are particularly strong around certain frequency ranges, corresponding to stressed syllables, syllables, and phonemes (Leong et al., 2017). This early entrainment suggests that infants are able to neurally track speech, thus supporting early language development. Indeed, the initial literature in this field indicates a link between speech-brain-coherence and early language acquisition (Menn et al., 2022). This might suggest that infants with greater tracking may have an early advantage for language acquisition. In the current study we longitudinally assess whether individual neural tracking of speech trajectories relates to individual differences in later language skills. Two key questions are asked: (i) How does neural tracking change in early brain development (6, 9, 12 months of age)? (ii) How does neural tracking measures relate to later language growth (measured in the second year of life)? We expect that at different ages, different rates might drive tracking mechanisms. Moreover, those children with better tracking abilities across early life will show greater language growth/skills in later language measures.

We collected EEG data ($N = 129$) from monolingual Dutch infants while they listen to 5-minutes child-directed stories at three different timepoints in the first year of life (6, 9, 12 months). Additionally, CDI language development data were collected in the second year of life (12, 18, 24 months – last datapoint to be concluded soon). Interestingly, significant clusters of speech-brain-coherence (i.e., computed as difference between the real data and shuffled data) were only found at 6 months (Figure 1) at the syllable (3.5–5 Hz) rate. Neural data from these clusters were extracted and correlated to later language growth, computed as the difference in CDI scores for both perception and production between sessions 12 and 18 months. No significant correlations were found. Thus, we did not replicate the relation between speech-brain-coherence and later vocabulary development in this longitudinal large-sample dataset. Further analyses, expected to be completed before July 2026, include the addition of a third CDI datapoint at 24 months and will allow us to model language growth more precisely by means of growth curve analyses.

Abstract 2

Title: Cortical Tracking of Speech as a Neuromarker of Individual Language Development in Monolingual and Bilingual Infants

Cortical tracking of speech (CTS) refers to the synchronisation between the endogenous neural oscillatory activity and the temporal dynamics of the speech signal. This synchronisation occurs simultaneously at multiple speech rates corresponding to different levels of the linguistic hierarchy, so CTS is viewed as a critical mechanism for successful encoding of speech and its segmentation into meaningful linguistic units. Accordingly, efficient CTS has been linked to successful speech comprehension, whereas deficits in CTS are associated with language disorders.

More recent studies have shown that CTS can be successfully captured in young infants. Moreover,



there are emerging findings of concurrent and longitudinal relations between CTS and infants' language abilities, such as vocabulary size, suggesting that CTS may serve as a reliable neuromarker for language development. Nevertheless, this evidence remains limited, and it lacks consensus regarding the specific approaches for measuring CTS, and the maturational and environmental factors that can influence CTS across development.

We are conducting the Birth-to-School project, which aims to address these questions by assessing CTS longitudinally in monolingual and bilingual infants. Here, specifically, we focus on CTS to infants' native language (i.e., monolinguals' only and bilinguals' dominant language) at 4 and 7 months and expressive vocabulary size at 18 and 24 months.

To measure CTS, infants listened to ~5 minutes of continuous naturally-produced infant-directed speech while their neural activity was recorded using EEG. We calculated temporal response functions (TRFs) at the delta and theta frequency bands. TRFs are weights from a ridge regression model between the amplitude envelope of speech and the EEG signal. Vocabulary was measured with the Spanish and Basque adaptations of the MacArthur-Bates CDI.

Preliminary analyses (47 monolinguals and 35 bilinguals) indicate that CTS did not differ significantly across ages and groups, with no significant age by group interaction for both frequency bands (all $F < 1$, all $p > .5$). Correlational analyses showed moderate consistency in CTS between ages (delta $r = .267$; theta $r = .327$), but there were no relations between CTS and vocabulary size (all $r < .2$). We will further test these relations in our full sample (expected $n = 100$). We will discuss our findings in relation to the growing literature on CTS in young infants and the challenges for identifying neuromarkers of individual language abilities in infants growing up in multilingual settings.

Abstract 3

Title: Electrophysiological maturation predicts neural speech processing in infancy

The infant brain is not fully matured at birth. During the first years of life, the brain undergoes rapid electrophysiological development, shifting from dominant low-frequency activity to greater high-frequency activity (Schaworonkow & Voytek, 2021; Le Van Quyen et al., 2006). Crucially, these electrophysiological properties of the infant brain shape information processing, such as speech perception. It has therefore been hypothesized that neural maturation directly influences early language development (Menn et al., 2023). However, direct empirical evidence for this relationship remains scarce. Here, we test this hypothesis by examining whether individual differences in neural maturation associate with neural speech processing in infancy.

We analyzed EEG data from a sample of 79 Dutch-learning 10-month-old infants, each tested twice on the same protocol within approximately one week, yielding $n = 141$ artifact-free datasets. During each session, EEG was recorded during two tasks: (1) a visual task during which infants watched toys on a screen, used to assess neural maturation, and (2) a speech task during which they listened to Dutch nursery rhymes, used to measure speech processing.

Neural maturation was quantified using frequency analyses of EEG. We measured the individual's peak frequency in the infant alpha range from 4–9 Hz (Corcoran, et al., 2018), and the aperiodic (1/f) slope of the EEG power spectrum, which captures the relative balance between high- and low-frequency activity (Donoghue et al., 2020). A steeper slope reflects more low-frequency activity while a flatter slope reflects increased high-frequency activity, indicative of neural maturation. Speech processing was assessed using speech-brain coherence, which captures the



synchronization between neural activity and the speech envelope—a proposed mechanism underlying speech processing (Meyer, 2018; Giraud & Poeppel, 2018). Coherence was measured at three linguistically relevant rates: prosodic (1–3 Hz), syllabic (3–5 Hz), and phonemic (5–15 Hz). Higher coherence indicates stronger speech tracking and thus more robust speech processing. Analyses revealed a significant relationship between aperiodic slope and speech-brain coherence, specifically at the phoneme-rate. Infants with a flatter aperiodic slope, indicative of a more mature brain (greater high-frequency activity), showed stronger speech-brain coherence at the phonemic rate ($t = -2.28$, $p = .024$) (Figure 2). In contrast, individual alpha frequency was not significantly related to speech-brain coherence at any rate (all $p > .8$).

These findings suggest that individual differences in electrophysiological maturation already associate with early speech processing, supporting a direct link of EEG maturation in shaping infants' speech processing, and potentially language acquisition. In a next step, we will run the same analysis in the Youth dataset, where >1000 infants have been followed longitudinally, with EEG measurements at 5 months, 10 months, and 3 years, and behavioral follow-up data on vocabulary development using the CDI and PPVT. This will allow us to assess EEG maturation longitudinally, and associate it with neural speech processing and further language development.

Symposium 7.4 - Naturalistic social interaction in atypical development

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Summary

Development unfolds in a cluttered natural environment. Social signals from caregivers help to cut through the noise, orienting infants to stimuli relevant to learning. There is a dearth of research examining perceptual input during everyday interaction in atypical development: Most studies take place in controlled settings, such as trial-based tasks. We address this gap by implementing wearable recording devices in caregiver-child play, quantifying how microlevel behaviors create learning opportunities. Paper 1 describes how child and parent object handling is associated with visual object dominance in children with Down syndrome. Paper 2 illustrates the relations between infant posture, face looking, and joint attention in infants with genetic predisposition for ASD. The final paper explores how caregiver-child contingent behavior leads to word learning in ASD. The discussant, an expert on atypical development, will describe implications for clinical and developmental science.

Details

Abstract 1, Dyadic sensorimotor behaviours of young typically developing children and children with Down syndrome: Object dominance and motor handling:

Children's everyday visual environments are often considered cluttered and ambiguous, yet young children demonstrate remarkable learning abilities. Research with typically developing (TD) toddlers revealed that during parent-child interaction, toddlers' egocentric visual scenes are less cluttered than expected, often featuring a single, large, dominant object (Yu & Smith, 2012). These



object-dominant events are closely linked to attention and learning, and have been shown to be self-generated, often via manual handling. Here, we expand our understanding of object-dominant events to a neurodivergent group who experience pervasive and persistent motor challenges early in life – young children with Down syndrome (DS).

Fifteen TD young children (17-27 months) were matched on mental age to 15 children with DS (36-58 months), using the Mullen Scales of Early Learning (Mullen, 1995). Each parent-child dyad participated in a six-minute table-top play session with three objects. Handling of objects and child's gaze were manually annotated, and object sizes in children's visual scenes were calculated using head-mounted eye-tracking and a custom-trained machine learning model (YOLOv11 with segmentation). Object-dominant events were defined as moments when (1) the absolute size of the largest object in view comprised at least 5% of the image; (2) the relative size of the largest object was greater than 50% of all other objects in view; and (3) it lasted at least 500ms.

Although we hypothesised that children with DS would show fewer object-dominant events, no differences emerged between the groups in how often these occurred (approximately every 8 seconds), their duration (just over a second), or the proportion of play they occupied (around 20%). However, the dominant objects during these events were significantly larger for children with DS ($Mdn=7.82\%$, $IQR=3.80\%$) than TD children ($Mdn=7.20\%$, $IQR=2.96\%$); $b=-0.10$, $SE=0.04$, $t(26.44)=-2.46$, 95% CI [-0.18, 0.02], $p=.021$. The maximum size the dominant object reached was also significantly larger for children with DS (DS: $Mdn=9.84\%$, $IQR=7.41\%$; TD: $Mdn=8.78\%$, $IQR=5.38\%$); $b=-0.15$, $SE=0.06$, $t(27.06)=-2.60$, 95% CI [-0.26, -0.04], $p=.015$ (Figure 1A).

Next, consistent with our hypothesis, children with DS handled the dominant object significantly less ($M=61.21\%$, $SD=21.40\%$) than TD children ($M=68.31\%$, $SD=17.40\%$); $OR=1.33$, $SE=0.10$, $z=3.85$, 95% CI [0.19, 0.28], $p=.003$. However, they handled non-dominant objects during object-dominant events more ($M=37.46\%$, $SD=19.38\%$) than TD children ($M=31.22\%$, $SD=20.18\%$), although this only approached significance ($OR=1.26$, $SE=0.09$, $z=3.09$, 95% CI [0.30, 0.40], $p=.055$). Interestingly, there was no significant difference between groups in handling of the dominant object when it reached its maximum size ($b=-0.04$, $SE=0.07$, $z=-0.59$, 95% CI [0.92, 1.15], $p=.557$). Furthermore, consistent with our hypothesis, parents of children with DS handled objects significantly more during object-dominant events. Both handling of dominant objects (DS: $M=26.56\%$, $SD=21.98\%$; TD: $M=23.26\%$, $SD=15.00\%$); $OR=1.33$, $SE=0.10$, $z=3.85$, 95% CI [0.19, 0.28], $p=.003$, and handling of non-dominant objects (DS: $M=36.20\%$, $SD=18.33\%$; TD: $M=19.32\%$, $SD=14.49\%$); $OR=2.55$, $SE=0.19$, $z=12.59$, 95% CI [0.16, 0.20], $p<.001$.

These findings suggest that ability-matched young children with and without DS show differing patterns of visual object dominance, and varying handling behaviours during these moments. These differences may shape how children with DS interact with and experience the world around them.

Abstract 2, Within-infant variability in attention across sitting postures in EL and LL infants:

Background



Infants' achievement of independent sitting transforms how they engage with the environment (Kretch et al., 2021), expanding their visual field and freeing their hands for object exploration (Jarvis et al., 2020; Luo & Franchak, 2020), thereby increasing opportunities for coordinated visual attention (CVA; Yu & Smith, 2017). Caregivers provide richer input when infants sit independently (Kretch et al., 2022a), including more object labeling (Kretch et al., 2025). Infants orient less to caregivers and objects in supported sitting, and caregivers touch toys more frequently (Kretch et al., 2022b). Sitting onset and quality predict subsequent language skills (Libertus & Violi, 2016), suggesting a developmental cascade from motor abilities to social-communicative learning. This is particularly relevant for infants at elevated likelihood for autism spectrum disorder (ASD), who frequently show early motor differences (Bhat et al., 2012) and for whom sitting predicts social communication (LeBarton & Iverson, 2016). However, little is known about how sitting posture shapes attention during play in infants at elevated (EL) and low likelihood (LL) for ASD. This study examines infant attention to toys and faces and CVA as a function of sitting posture.

Methods

EL and LL 8-month-old infants and their caregivers played with toys while wearing head-mounted eye trackers (Table 1). Frame-by-frame coding identified each partner's gaze target (i.e., toy or face). CVA was defined as frames when both looked at the same toy simultaneously. Coders also recorded infant posture in each frame. Posture was classified as supported sitting (assistance from caregiver, external support, or infant's hands), independent sitting, or other (supine, prone, crawl, stand). Analyses used generalized linear mixed-effects models accounting for age, group, and motor abilities indexed by Bayley Scales of Infant Development Fine and Gross Motor raw scores.

Results

Infant posture differed by group ($F(1,77) = 4.02, p < .05$), with EL infants spending less time in independent sitting than LL infants. At the group level, there were no significant effects of posture, group, age, or motor abilities on toy attention ($ps > .29$), face attention ($ps > .12$), or CVA ($ps > .38$). However, post-hoc chi-square analyses revealed robust within-infant variability. Supported vs. independent sitting was associated with significant differences in toy attention for 67% of infants, face attention for 65%, and CVA for 91% (Figure 1B).

Discussion

Despite group differences in sitting, posture did not predict toy attention, face attention, or CVA at the group level. This aligns with evidence that any sitting posture facilitates CVA (Kretch, 2025). Yet the substantial within-infant variability indicates that posture shapes attention for many infants, even if these effects are not captured by likelihood for ASD, age, or motor abilities. These individual differences may reflect how posture interacts with caregiver behaviors, which shift with infants' sitting status (Kretch et al., 2022a). Reduced independent sitting in EL infants may signal early motor differences (Landa & Garette-Mayer, 2006) that alter opportunities for caregiver input, potentially initiating longer-term cascades on social learning (Bradshaw et al., 2022). Further examination of posture-related attention may elucidate mechanistic pathways of emerging social-communication abilities.



Abstract 3, Contingent caregiver naming has differential effects in children with and without ASD:

Atypical language development is common in ASD, though the specific etiology is unknown (Iverson et al., 2023). Typically developing (TD) children learn words by forming connections between caregiver speech and objects in view (Bloom, 2000). Longer duration of child attention to named objects (“targets”) is associated with vocabulary growth across infancy (Yu et al., 2019). This learning process is modulated by the contingency of caregiver behavior: Caregivers can provide richer learning input by coordinating their speech with children’s activity, e.g., naming an object that is already in view (Bianco et al., 2025). Prior work indicates that parents of children with ASD tend to be more directive during toy play, often introducing a new object to the interaction instead of engaging with objects already in children’s focus (Steiner et al., 2018)

We hypothesize that language impairment in ASD emerges from differences in everyday perceptual input for learning. As such, we predict that children with ASD will show diminished target attention during caregiver naming in naturalistic caregiver-child interaction. Further, we predict that contingent naming will be less common in the ASD group. We will also explore whether contingent naming has differential effects on target attention in the ASD and TD groups.

Fourteen children with ASD (*Age*=38.1 months) and their caregivers played with 24 toys. A language-matched group of TD toddlers (*n*=36, *Age*=18.8 months) also participated. Children wore head-mounted eye-trackers that measured gaze location during play. Our analysis focuses on the temporal alignment of child toy fixations and caregiver utterances that included a toy name (“naming instances”). To measure word learning input, we defined a 3-second interval from the onset of each naming instance and calculated the proportion of each interval that children attended to the target toy. To examine effects of behavioral contingency, we divided naming instances into three contingency types. In child-led instances, the child was already looking at the target object at the onset of naming. In caregiver-led instances, the child switched attention to the target object after the caregiver already started speaking. In non-contingent instances, the child did not look at the target object at all.

In line with our prediction, children with ASD had lower target attention across all instances than TD children ($p < .01$). In both ASD and TD groups, non-contingent instances occurred most frequently, followed by child-led instances, then caregiver-led instances. Further, there was no group difference in the duration of target attention for caregiver-led instances. However, in child-led instances, TD children had longer target attention durations than children with ASD ($p < .01$; Figure 1C).

Our results indicate that contingent naming was equally prevalent between groups. However, children with ASD were less attentive to target objects than TD children. This difference was particularly stark in child-led naming instances, where caregivers referred to objects already in children’s view. In the future, we will explore behavioral differences underlying this discrepancy – how quickly caregivers follow children’s lead, and what behaviors lead to contingent naming, e.g. child object holding. This line of inquiry is crucial for developing ecologically valid language interventions.



Symposium 7.5 - Where infants sleep: parental decisions, cultural norms, and developmental outcomes

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Summary

This symposium brings together three studies examining why families from different contexts choose particular infant sleep arrangements, and how these practices shape long-term developmental outcomes. The first study conducted in the US explores psychological, practical, and belief-based factors shaping maternal choices about infant sleep location. The second cross-cultural study examines day- and nighttime sleep arrangements and their relation to child autonomy. The third longitudinal Dutch cohort study investigates whether early room-sharing predicts adolescent mental wellbeing and behavior, considering the role of child self-regulation and maternal caregiving. Together, these studies use diverse populations and methods to demonstrate how infant sleep practices are embedded within broader caregiving goals and cultural meanings, and how early sleeping arrangements may relate to later behavioral and emotional outcomes.

Details

Abstract 1, Factors Influencing Maternal Choices about Infant Sleep Location

Introduction: Currently in the U.S., pediatric/public health recommendations include strong recommendations for roomsharing without bedsharing with infants for at least 6 months to 1 year (Moon et al., 2022a). While bedsharing is a culturally-expected norm in many of the world's cultures (Mileva-Seitz et al., 2017), it is not the case in the U.S. even though most U.S. families engage in bedsharing at least some of the time (46-62%; AASM 2024; Bartick et al., 2022). What factors influence parental choice of infant sleep location (ISL) in the U.S. that may explain the discrepancy between public health advice and family practices? We hypothesize that (1) planning for ISL predicts satisfaction with ISL, (2) satisfaction with ISL depends on the ISL, (3) preference for ISL predicts satisfaction with ISL, and (4) when parental beliefs match their ISL then satisfaction with ISL is higher. Many other variables contributing to maternal orientations and satisfaction with ISL are explored as well. **Method:** Participants were recruited from public Facebook groups targeting families interested in cosleeping (including bedsharing) and sleep training. Surveys were completed by 266 mothers of infants between 0 and 12 months (mean age 6.3 months, SD=3.38). Surveys included questions about breastfeeding status, ISL, infant bedtime habits and behaviors, questions from the Infancy Parenting Styles Questionnaire (IPSQ; Brown & Arnott, 2014), questions from the Brief Infant Sleep Questionnaire (BISQ; Mindell et al., 2019), and questions about satisfaction with ISL, preference for ISL and whether ISL was a problem. **Results:** Our first hypothesis was supported—planning for ISL explained 14% of the variance in satisfaction with ISL, ($R^2 = .38$, $F(1,140)=23.56$, $p<.001$). Our second hypothesis was also supported. ISL predicted satisfaction with ISL, with mothers of infants sleeping in a crib being significantly more satisfied than mothers of bedsharing infants ($F(5,250)=4.24$, $p<.001$). We also found support for the third hypothesis, where maternal preference for ISL significantly predicted ISL, ($R^2 = .66$,



$F(1,254)=191.83.56, p<.001$) and explained 43% of the variance in ISL. Finally, we determined whether mothers' beliefs matched their choice of ISL. When they did (high in parent-led beliefs with solitary-sleeping infant or high in parent-led beliefs with bedsharing infant), satisfaction was higher ($M=4.46, SD=.117$) than when beliefs did not match ISL ($M=4.21, SD=.08$), $t(1,168)=-1.85, p<.03$. The effect size was large, Cohen's $d=.841$. Data collection is complete and more analyses are in process to unpack factors contributing to preference for and satisfaction with ISL, including the important role of breastfeeding in roomsharing and bedsharing. **Discussion:** The current study found significant differences among attitudinal and behavioral responses of mothers of bedsharing and solitary-sleeping infants. While it has long been known that breastfeeding is related to bedsharing, the role of maternal parenting beliefs has been lacking in the literature. The strength of this study is its use of existing measures to provide novel answers to factors influencing parental choice of infant sleep location.

Abstract 2, Day- and nighttime sleeping arrangements and children's autonomy worldwide

Infants' and children's sleeping places are a constant topic of debate, for families but also for professionals. The current North American recommendations for infants' sleeping places indicate that infants should share a room, but not the sleeping surface with their parents or others for the first six months (see CPS, 2021; Moon et al., 2022). While the pediatric rationale for this is avoiding sleep-related deaths (Moon et al., 2022), and parents believe that their children's independence or autonomy is promoted by sleeping separately (Morelli et al., 1992; Yang & Hahn, 2002). However, there are mixed empirical results on this (e.g. Keller & Goldberg, 2004) and bed-sharing is the norm in many other areas of the world (Owens, 2004). Cross-culturally, parents may not consider independence or autonomy development when selecting their child's sleeping place (Morelli et al., 1992). Moreover, there may be different views on the usefulness of sleeping separately for developing autonomy. Additionally, many studies take only nighttime sleeping into account, while day- and nighttime sleeping arrangements can vary substantially (e.g. Abels et al., 2021). For example, Abels and colleagues (2021) that Norwegian children often bed-share at night, while they sleep in a stroller outside during the day. While the main motives for these sleeping place choices mentioned by the participants were generally not related to the children's autonomy, they may still have an effect on the child. The additional, complementary or contradictory effects of daytime sleeping arrangements on autonomy development are even less clear. Our current study therefore aimed at exploring day- and nighttime sleeping practices of families across the world and how this relates to caregivers' reported autonomy support and child autonomy. The data is collected online with questionnaires in several languages, such as Norwegian, English, Spanish, Tagalog etc. aiming at a diverse sample of caregivers from different parts of the world. The questionnaires are based on existing questionnaires on autonomy (Owens, Spirito & McGuinn, 2000; Steinberg & Silverberg, 1986), caregivers' autonomy expectations (e.g. Greenberger & Goldberg, 1989), autonomy support (Mageau et al., 2015) and the connection between sleeping arrangements and autonomy (Keller & Goldberg, 2004). Data analysis are expected to be completed in spring 2026, and the results will be discussed during the presentation.

Abstract 3, Longitudinal associations between parent-infant room-sharing and adolescent mental wellbeing and behavior: the role of childhood self-regulation and maternal caregiving behavior



Introduction: Parent-infant room-sharing without bed-sharing is advised for at least the first 6 months postpartum to reduce the risk of sudden infant death syndrome. Nonetheless, overall adherence to these recommendations remains low, often due to concerns about potential long-term effects on children's independence and behavior. However, research has not thoroughly examined how early-life room-sharing actually relates to children's developmental outcomes. Therefore, the present study investigates long-term associations between parent-infant room-sharing in the first 6 months postpartum and adolescent mental wellbeing and behavior, as well as the role of early childhood self-regulation and maternal caregiving behavior in these associations.

Hypotheses: Based on our previous findings within the same cohort during middle childhood, room-sharing in infancy was expected to be unrelated to depressive symptoms, anxiety, perceived stress, and internalizing and externalizing behavioral problems in adolescence. Contrarily, room-sharing was hypothesized to be associated with more prosocial behavior, optimism, and happiness in adolescence. Further, we expected early childhood self-regulation to mediate the associations between room-sharing and positive adolescent outcomes, and maternal caregiving behavior to moderate the relation between room-sharing and child self-regulation, with the association being stronger when maternal quality of caregiving behavior was higher (see Figure 1). **Study population:** Participants were 16-year-old adolescents whose mothers were enrolled in an ongoing longitudinal prospective cohort study examining the influence of early life environmental factors and individual characteristics on behavioral and physical development. At age 16, 65% of the adolescents ($n = 125$) participated in this specific measurement round. **Methods:** From childbirth up to 6 months postpartum, mothers completed a daily diary on infant sleep. In addition, mothers and their children were visited at home at 5 weeks, to observe maternal caregiving behavior, and again at 30 months postpartum, to observe child self-regulation. At age 16, children completed a battery of online questionnaires to assess their mental wellbeing and behavior. **Results:** Results show that room-sharing was significantly related to fewer internalizing behavior problems in adolescence. Room-sharing was not related to depressive symptoms, anxiety, perceived stress, prosocial behavior, externalizing behavior problems, or happiness in adolescence. Optimism was excluded from the analyses because of poor internal consistency. No mediating effects were found of early childhood self-regulation: room-sharing did not significantly predict self-regulation and self-regulation was not associated with adolescent outcomes. Finally, analyses revealed no significant moderating effect of maternal caregiving behavior on the association between room-sharing and self-regulation in early childhood. **Conclusions:** Our findings challenge the assumption held by some that room-sharing may impede children's behavioral and emotional development. In fact, our results cautiously suggest that room-sharing may actually benefit children in the long run, as those adolescents with more frequent early-life room-sharing experiences reported fewer internalizing behavior problems.

Symposium 7.6 - Looking-While-Listening in context: design, implementation, and convergence of word recognition paradigms across languages and modalities

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Summary



Developmental research on infant word recognition has advanced dramatically over the past decades, from hand-coding videos, to online eye-tracking, and to automated gaze detection systems. This symposium brings together the current efforts aimed at standardising, validating and broadening the generalisability of word recognition across populations and languages. We (1) examine the congruence between eye-tracking data from infants and parent estimates of their word knowledge; (2) evaluate how an existing gaze-direction analysis tool generalises to various populations and test ways to improve its performance; and (3) introduce a remote testing study that investigates children's word recognition across ages, languages and cultures. The discussant, an expert in eye-tracking methods, will integrate and refine the key points made in the three presentations, providing a cohesive picture of how we can generalize our understanding of word recognition across modalities and linguistic contexts.

Details

Abstract 1, Title: Capturing Early Vocabulary Across Contexts: What Parents Report vs. What Infants Show

Accurate assessment of early vocabulary is a persistent challenge in developmental science. While parental reports like the MacArthur-Bates Communicative Development Inventories (CDI) provide cost-effective, broad measures of vocabulary, they are subject to reporter biases. Conversely, behavioral measures like the Looking-While-Listening (LWL; Fernald et al., 2008) paradigm offer objective, time-course data but are limited by the number of items they can test and the indirect nature of inferring knowledge from gaze. This study bridges these methodologies by examining the convergence between parental reports and eye-tracking measures in 28 Korean-learning infants (Mage = 13.2 months, SD = 0.41), investigating how assessment format, item difficulty, and semantic category influence congruence.

We compared infants' real-time word recognition with parental reports using two formats: the full Korean CDI (MCDI-K) and a shorter, study-specific checklist containing only the 40 target words (30 nouns, 10 verbs) from the eye-tracking task. For the behavioral measure, we evaluated convergence using three distinct gaze-analysis methods: (1) proportion of target looks, (2) proportion of target looks adjusted by subtracting the proportion of target looks during baseline, and (3) proportion of looks to the target image adjusted by subtracting the proportion of looks to the image when it served as a distractor.

Our results reveal three systematic patterns of convergence and divergence. While parents were consistent across CDI versions, the target-word checklist demonstrated significantly stronger convergence ($r = .66$) with eye-tracking data than the full CDI, particularly when gaze data were corrected for baseline visual biases (Figure 1). This suggests that focused checklists may reduce the cognitive load on parents, yielding more precise estimates of current knowledge.

Second, we found the reporting accuracy varied by Age of Acquisition (AoA). Contrary to the expectation that well-known words would show the highest agreement, parents systematically over-reported knowledge of early-acquired words. Specifically, for words with earlier normative AoA, parents frequently reported comprehension even when infants showed no significant target looking. In contrast, parental reports for later-acquired words were more conservative and aligned more closely with eye-tracking data, suggesting that parents may infer knowledge of "easy" words based on routine contexts rather than genuine observation of lexical processing.

Third, our analysis of semantic categories challenges the "verb-friendly" hypothesis often



associated with Korean (Table 1). While parents reported a balanced knowledge of nouns and verbs, infants' gaze behavior showed a significant noun advantage, with robust recognition of nouns but weaker performance on verbs. This discrepancy suggests that parental reports may capture context-dependent comprehension of verbs that do not translate to the decontextualized, static environment of standard eye-tracking tasks.

These findings demonstrate that parental reports and eye-tracking capture intersecting dimensions of early word knowledge. Parental reports reflect consolidation-level knowledge: words robustly mapped across contexts and reliably recognized over time. Eye-tracking captures emergence-level recognition: the detectable moment when attention reorients toward a named referent in controlled settings. Future studies should index what developmental stage each method captures, rather than asking which is more valid, and deliberately sample across both contexts to build complete developmental trajectories.

Abstract 2, Title: Evaluating and Adapting iCatcher+ with Korean Infant Data: A Transfer Learning Approach

Developmental scientists try to understand infants' thinking by looking at where they focus their gaze. Traditionally, this has involved manually labeling video frames, which takes a lot of time and effort and can lead to inconsistencies among different people. However, recent advancements in computer vision and machine learning now allow for automated gaze analysis from video data with greater accuracy. One such tool, iCatcher+, was developed to automatically estimate infants' gaze direction from video input (Erel et al., 2023). It has shown strong performance across various datasets, including both online and lab settings. iCatcher+ uses convolutional neural networks (CNNs) and other various machine learning architectures for per-frame gaze direction classification to capture how infants move their gaze over time and space. It was trained on datasets like Lookit, Senegal, and California-BW, which represent different infant populations. However, these datasets mainly reflect limited cultural and environmental contexts. Recent studies have started to explore how differences in population or recording conditions affect automated gaze classifiers. For instance, Hagihara et al. (2024) assessed iCatcher+ and other algorithms using adult webcam data meant to mimic common noise factors in online infant studies. They found that environmental factors like lighting and camera distance greatly impacted model accuracy. These results highlight the necessity of testing model stability in varied contexts. In this study, we evaluate the performance of iCatcher+ on a dataset of 27 Korean infants (Mage = 13.2 months, SD = 0.41) to further explore its ability to work across different cultures. This study is based on 30 video recordings of infants collected at Chosun University, Korea, during experiments designed to examine early language learning. To evaluate accuracy, we compared the predictions from iCatcher+ to manually coded labels created by trained human annotators.

Our findings showed a significant drop in performance when using iCatcher+, which was originally trained on the Lookit dataset, on the Korean infants' data. The overall accuracy fell from about 88% (on the Lookit test set) to 71% on the Korean dataset. The largest decline was seen in detecting rightward gazes, where the model accurately identified only around 68% of those gazes, often mislabeling them as "away." These results suggest that iCatcher+ may have picked up specific visual features from its training dataset that do not transfer well to different cultural or



environmental contexts, demonstrating a common domain shift effect (Ben-David et al., 2010). To address these issues, we applied transfer learning with a fine-tuning method (Hinton et al., 2006, Oloyede, 2024). Retraining the model with a small, labeled set of Korean data greatly improved overall accuracy and reduced directional bias while keeping performance stable on new participants. We plan to expand the dataset to include over 100 additional participants to further validate and strengthen the model's cross-cultural robustness. Overall, these results show the importance of using culturally diverse training data and adaptable modeling methods to create gaze estimation systems that work well across different populations and settings in developmental research.

Abstract 3, Title: Investigating familiar word recognition in infants across ages and languages in a remote online study: The ManyBabies-AtHome: Looking-While-Listening project

Current and previous worldwide collaborations between developmental researchers have begun to implement remote studies to enable engagement from a wider population of researchers and participating families (Zaadnoordijk et al., 2021). However, while large-scale collaborations and remote data collection hold many promises, they are especially challenging when studying language (and by extension, familiar word recognition). Word recognition studies about infants learning different languages within the same study are rare (e.g. Ramon-Casas et al., 2009), and experimental design and analytic decisions vary considerably between studies (Von Holzen & Bergmann, 2021; Zettersten, et al., 2021), rendering comparison extremely difficult. Additionally, there also exists discrepancies between the measures used to assess word recognition in children (e.g., Houston-Price et al., 2007; Potter & Lew-Williams, 2023).

To address these shortcomings, the ManyBabies-AtHome: Looking While Listening project aims to study the developmental trajectory of word recognition in infants learning different languages across different ages, using an online version of the traditional Looking-While-Listening paradigm (LWL; e.g., Golinkoff et al., 1987; Fernald, et al., 2008). Specifically, we aim to examine whether children's word recognition as indexed by speed and accuracy of their looking toward a named referent varies as a function of (1) age of the child, (2) whether their caregiver indicated that they understand the word, and (3) the language they are learning.

Infants between 10-24-months will be recruited to participate in this study, from various countries and learning various languages, with the research team recruiting 48 participants across the age group for each language. In the online LWL task, infants will be shown two (presumably) familiar objects on the screen, and hear the label of one of the objects embedded in a carrier phrase. In order to ensure that the task can be adapted for cross-linguistic contexts, one-half of the objects will be standardised across languages, while the other-half will be chosen by researchers for each individual language. The experiment will be implemented via E-Babylab (Lo et al., 2024), with the integrated Webgazer application (Papoustaki et al., 2016) automatically estimating infants' looking on the screen using the participant's webcam. Additionally, caregivers will also report children's knowledge of the presented words through a questionnaire. Preliminary piloting with Korean infants indicates that this approach is feasible and yields dense, high-quality data.

We predict that (1) infant word recognition accuracy and speed will increase as they grow older and



(2) will be higher for words indicated by parental report as known to the child. However, (3) there may be variation in this relationship across languages due to cultural and lexical differences, though we cannot currently speculate on the direction or magnitude of this potential effect. Our approach has broad implications, as resource-friendly adaptations to local contexts remain a challenge for cross-linguistic and cross-cultural work. Our stimulus development protocol will also be useful in multilingualism research, where investigators can then select the suitable languages from an existing item pool. Additionally, this project's outcome will establish the largest cross-linguistic, cross-cultural dataset on the development of infant word recognition.

Symposium 8.1 - Effect of multimodal caregiver complexity on infant attention and learning during naturalistic interactions

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Summary

Infant attention has long been characterized in controlled settings, revealing a preference for stimuli that optimize learning through intermediate complexity. Yet real developmental learning unfolds within rich, dynamic caregiver–infant interactions. This symposium integrates behavioural and neural insights on the effect of caregiver complexity on infant attention. Using manual and automated behavioral measurement, we illuminate how infants allocate attention within naturalistic interactive contexts and how caregivers shape these attentional patterns using multimodal cues. Together, these approaches offer a more ecologically grounded understanding of the mechanisms driving early attention and learning.

Details

Abstract1: From salience to semantics in naturalistic interactions: How attention is scaffolded using multimodal behavioural complexity

Infants learn particularly effectively in live, face-to-face interactions, yet the underlying mechanisms that make these exchanges so powerful remain incompletely understood. In particular, little is known about how caregivers dynamically shape the sensory and informational environment across multiple modalities and timescales, and how these moment-by-moment adjustments relate to infants' attention. In this study, we examine how caregivers modulate the predictability and informational structure of both their speech and their visual behaviour in direct response to infants' fluctuating attentional engagement during naturalistic play.

We analysed semi-naturalistic tabletop interactions from 67 mother–infant dyads (33 at ~5 months; 34 at ~15 months), while they engaged in a table-top joint play with toys. Infants' visual attention to objects and to their mother's face was manually coded frame-by-frame at 50 Hz. Maternal behaviour was characterised using a multimodal feature-extraction pipeline integrating computer vision, automated speech processing, and information-theoretic analyses.



From the audio stream, maternal vocalisations were automatically transcribed and timestamped (WhisperX), enabling mapping between acoustic features and linguistic content. We computed spectral flux for both maternal speech and ambient noise as a measure of low-level auditory variability, capturing rapid fluctuations in acoustic salience that influence the predictability of the auditory environment. At the linguistic level, transcripts were analysed to derive speech information rate, semantic surprisal, and object-naming events, allowing us to quantify how the informational density and semantic predictability of speech changed moment-by-moment. Maternal hand and face movements were derived from facial features and pose tracking algorithms (mmpose), and facial expression novelty was computed as a measure of unpredictability in expressive behaviour. These visual features, like the auditory ones, allowed us to examine how caregivers modulate both low-level motor variability and higher-order expressive dynamics as infants engage with objects.

To capture the temporal organisation of these interactions, we computed cross-correlations between continuous infant gaze and multimodal maternal features across multiple lags. This approach enabled us to test how changes in maternal behaviour either precede or follow changes in infant attention, revealing the temporal structure of caregiver–infant contingency. We then performed cluster-based permutation to test significance against chance level.

Across both ages, we observed patterns of multimodal adaptation. When infants focused on objects, mothers reduced low-level sensory unpredictability—visible as decreases in acoustic flux and reductions in facial and hand movement—effectively stabilising the sensory environment. Conversely, increases in higher-level communicative signals, including object naming, speech information rate, and facial novelty, were associated with increases in sustained infant attention.

These findings show that early social interactions are not merely rich in information but are dynamically structured through predictable, multimodal adaptations that unfold over multiple timescales. Caregivers continuously adjust both the sensory variability and semantic content of their behaviour in real time, scaffolding infants’ attention and early learning through coordinated, multimodal tuning.

Talk2: The Role of Speech Complexity and Gestures in Children’s Word Learning During Shared Book Reading

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Shared book reading is a key context for early language development. It presents children with more complex language than everyday speech, exposing them to diverse vocabulary, varied sentence structures, and dialogical interactions. Previous studies have shown that children are sensitive to input complexity, attending most to material that matches their current capacity—neither too simple nor too difficult. They are also sensitive to social cues, such as gestures, which help guide attention and support learning. Yet little is known about how these factors interact in real time. How do children navigate rapidly changing streams of language and social signals? How



do they prioritize multiple cues? And how does existing vocabulary shape these attentional decisions?

To address these questions, we analyzed an existing naturalistic parent-child book-reading dataset. Sixteen English-speaking parent-child dyads ($M = 19.3$ months) read five wordless books for 10 minutes while both wore head-mounted eye-trackers, capturing moment-by-moment gaze data. Parent speech was transcribed, and both parent and child pointing gestures were coded. Because the focus of the study was on learning object names, all subsequent analyses centered on parent object-naming moments.

We focused on three questions: (1) How complex are the sentences parents produce? (2) How does linguistic complexity affect children's attention to the labeled target, and does this depend on children's existing vocabulary knowledge? (3) How do speech and gestures jointly modulate attention as a function of vocabulary?

Our results showed that (1) parents produced labels frequently ($M = 13.51$ labels/min) and used a wide range of sentence types (see definitions in Table 1), with a clear preference for medium-complexity forms: fragments (20%), copula constructions (27%), subject-predicate sentences (40%), and complex multi-verb sentences (13%). (2) Children's attention to named objects—measured as target looks within 3 seconds of utterance onset—remained relatively stable across sentence types (fragments: 47%, copula constructions: 49%, subject-predicate sentences: 47%, complex sentences: 38%). This pattern held for both low- and high-vocabulary children, despite differences in learning capacities. (3) However, when considering pointing cues (which co-occurred with object naming 61% of the time), we observed an interesting pattern: when no gestures were present, both high- and low-vocabulary groups showed reduced attention to complex sentences, indicating higher processing demands without additional support. When parental gestures accompanied naming, this decline was reduced; pointing substantially maintained attention on complex input for both groups. Interestingly, when children produced gestures themselves, the attention-boosting effects diverged by vocabulary level: low-vocabulary children's points boosted attention primarily for simple sentences, whereas high-vocabulary children's points increased attention for complex sentences. Together, these results show that gestures guide children's attention in ways that align with their processing capacities (Figure 1).

In sum, while parents tend to use medium-complexity sentences, children's attention is largely unaffected by complexity alone. When pointing gestures are considered, both parents' and children's gestures influence attention to the target under varying linguistic demands. Naturalistic book-reading data thus reveal how children with differing vocabulary levels use multimodal cues to navigate complex input and how these cues differentially scaffold early word learning.

Table 1. Selected CLAN measures.

Examples		MLU Words	MLU Morphemes	Total type	Total token	TTR	Density
Fragment	Cat!	2.41	2.58	22.82	38.64	0.67	0.30
	A cat!	(0.65)	(0.71)	(12.87)	(29.88)	(0.16)	(0.11)
Copula	It's a cat.	4.68	5.11	30.25	77.16	0.46	0.36
	This is a cat.	(0.59)	(0.63)	(11.46)	(45.97)	(0.15)	(0.07)
Subject-predicate	The boy has a cat.	5.67	6.32	57.78	145.73	0.44	0.39
	Can you say cat?	(0.62)	(0.74)	(19.99)	(73.86)	(0.11)	(0.05)
Complex	The boy enjoys hugging the cat.	7.58	8.46	39.18	74.80	0.62	0.45
	I know you love hugging cats too.	(1.16)	(1.38)	(17.25)	(55.33)	(0.15)	(0.05)

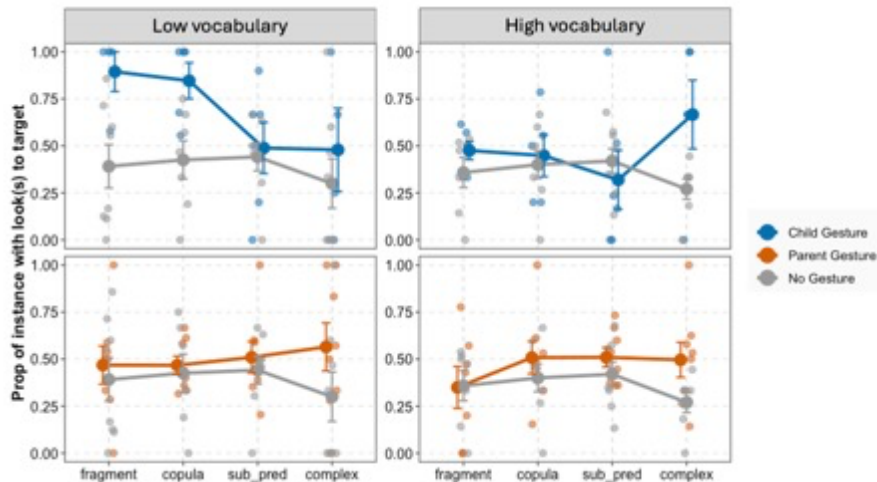


Figure 1. Without gestures, child attention declined for both vocabulary groups as sentence complexity increased. Parental gestures helped sustain child attention for complex sentences. Children's own gestures showed vocabulary-dependent effects: low-vocabulary children's points boosted attention for simple sentences, whereas high-vocabulary children's points boosted attention for complex sentences.

Talk3 Characterizing the emergence of Phase-Amplitude Coupling in the first year of life to understand attention in the infant brain

Authors: Tess Allegra Forest, Khula South Africa Data Collection Team, Laurel Gabard-Durnam, Kirsten Donald, Dima Amso

Abstract: Attention develops a great deal across infancy and can be conceptualized as an ongoing competition for neural resources within and between bottom-up and top-down signals. Adult EEG data show that low-frequency top-down oscillations from anterior brain regions modulate higher-frequency, bottom-up posterior oscillations via *phase-amplitude coupling*, or PAC. Adult and primate data show that the balance of top-down/bottom-up information shapes selective attention, such that stronger PAC results in stronger modulation of local, bottom-up signals. Using data from the Khula Study, a large-scale project designed to understand the pre-and postnatal factors that shape executive function development (Zeiff et al., 2024), we recently characterized the longitudinal emergence of phase-amplitude coupling over the first two years of life. Specifically, we calculated longitudinal PAC during resting-state EEG (N=278) at 3, 6, 12, and 24mos to offer novel insight into how attention is instantiated in the developing brain. Our results show that occipital alpha-gamma PAC decreases with age while frontal theta-gamma PAC increases, reflecting an expanding contribution of top-down on bottom-up brain function. Next, we asked whether the rate of change in occipital compared to frontal PAC related to infant's attention towards their caregiver in naturalistic, dyadic interaction as a way to understand how early



experiences change the rate at which this signature emerges. To do this, we hand-annotated infants' naturalistic interactions with their caregiver, and calculated both the entropy (unpredictability) of moment-to-moment caregiver behavior and infant looking towards their caregiver, before relating individual infants' rate of change in frontal PAC to their early attention shifting. We found that infants whose attention was more tightly coupled to shifts in the predictability of their environment showed accelerated developmental change in PAC. These results provide a compelling demonstration that more localized, bottom-up processing governs oscillatory activity in young infants, that longer-range top-down communication emerges later alongside behavioral evidence of top-down attention, and that our early interactions with our caregivers shape these developmental trajectories.

Although researchers have long assumed that infant-caregiver interactions are not linear or confined to a single behavioral channel, only recently has the field gained and applied the analytic precision needed to test this assumption. With advances in high-density, time-resolved measurement and analytic methods, a clearer picture has emerged: infant-caregiver interactions are multimodal and multi-scale, with complex temporal dependencies. We present a collection of work which demonstrates this picture. Using complementary, time-resolved methods, such as dynamic structural equation modeling, wavelet coherence with phase-angle metrics, information-theoretic time-series, and multilevel time-to-event models, these studies show that moment-by-moment patterns of facial affect, gaze, touch, vocal affect, RSA, and semantic signaling are interdependent within dyads, vary by context and timescale, and carry developmental signal. The key takeaways from this body of work are, in order: (1) early maternal facial stability and reduced infant affective volatility predict later child internalizing, independent of maternal mood; (2) RSA synchrony exhibits context- and timescale-dependent leader-follower shifts; (3) mothers dynamically modulate low- and high-level input to support infant attention; and (4) infants progressively decouple gaze and smile across the first year, particularly by partner type (mother, father, stranger). Together these findings argue for time-sensitive, dyad-centered biomarkers of regulation and risk.

Symposium 8.2 - Everyday face experiences across infancy: context, availability, and interactive dynamics

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Summary

Across early development, infants encounter faces in cluttered, dynamic environments, yet the structure of these real-world inputs and infants' engagement with them are only beginning to be understood. Paper 1 provides a developmental foundation using head-mounted camera recordings, revealing a shift from highly salient, close face input to more canonical, centred configurations across 2-9 months. Paper 2 examines face availability during playtime, demonstrating nonlinear, scene-location-specific changes across 2-30 months that align with emerging motor skills. Paper 3 focuses on moment-to-moment gaze dynamics during playtime across 12-30 months, showing that although faces are available, face looks are rare, intentional,



and coordinated with caregivers. These findings will be discussed in relation to dynamic systems theories of developmental change, the interaction of critical developmental tasks and goals during infancy, and the importance of early domain-relevant learning.

Details

Abstract 1, Daily Face Input in Young Infants Is Structured to Guide Attention to Faces: Visual experiences of faces play a crucial role in the development of face processing skills. Since the lack of early face experiences has long-term consequences for functional face processing (Maurer et al., 2007; Zohary et al., 2022), previous studies have investigated mechanisms that guide young infants' attention to faces. Infants show visual preferences for faces and face-like stimuli from birth (Johnson et al., 1991; Valenza et al., 1996), leading to controversy about whether face preferences are driven by intrinsic attentional biases to face configurations (Johnson et al., 2015) or by domain-general visual properties of the scene (Scott & Arcaro, 2023). Despite the accumulation of experimental evidence that young infants' attention to faces is mediated by visual properties such as bottom-up saliency (Frank et al., 2009; Franchak & Kadooka, 2022; Kwon et al., 2016), little is known about the visual statistics of infants' daily face input and how they change between early and late infancy. Here, we used head-mounted cameras to examine the developmental changes in the configuration of facial features and domain-general visual properties of face input in everyday environments.

We longitudinally collected daily infant-perspective video recordings from 2-3-, 5-6-, and 8-9-month-old US infants using head-mounted cameras. In total, we recorded 130 hours of footage from 26 infants. We performed semi-automatic face annotations on frames sampled at 1 Hz, yielding 79,344 face bounding boxes in 69,662 images. We analyzed the developmental changes in (1) the proportion of time with faces present, (2) temporal persistence of faces, (3) face proximity, (4) face saliency, (5) face centering, and (6) the visibility of facial features (eyes, nose, and mouth). Regarding face proximity, we calculated a depth map (Yang et al., 2024) and obtained the median depth value within the face region. Regarding face saliency, we calculated a graph-based visual saliency map (Harel et al., 2007) based on five low-level visual features (DKL color, intensity, orientation, flicker, and motion) and obtained the maximum saliency value within the face region.

We found that infant face input showed a developmental shift from attention-attracting visual properties to a canonical face configuration. The youngest infants' face input was characterized by more frequent and closer faces that were more temporally persistent and visually salient, suitable for guiding infants' attention to faces despite their limited visual acuity and attentional control. An additional control analysis revealed that the larger face region (due to closer positioning) for 2-3-month-old infants could not fully explain the age-related changes in face saliency, suggesting that faces were genuinely more visually prominent in the youngest infants' view. Older infants' face input was characterized by more frontal faces located at the horizontal center of the visual field, suitable for configural processing (Maurer et al., 2002). These findings indicate a curriculum of face experiences initially guided by domain-general visual properties, suggesting that the interplay between the developing visual system and dynamically structured face input supports the emergence of face processing skills.



Abstract 2, Nonlinear Changes in Face Availability During Naturalistic Playtime Across the

First Years: Insights From Head-Mounted Cameras and Automated Face Detection: Faces play a fundamental role in early development, shaping visual attention, social learning, and caregiver-infant interactions. Although there has been extensive research on face perception and social learning, the egocentric visual experiences of faces in everyday environments have emerged as an important area of inquiry only more recently. The availability of lightweight head-mounted cameras (headcams; Smith et al., 2015) in the past decade or so has provided novel opportunities to directly explore and characterise everyday face availability from the infant's own visual perspective.

Existing headcam studies of face availability fall into two categories - home-based and lab-based - with home studies capturing everyday experiences (~4-6 hours) typically showing a decline in the proportion of faces in infants' visual scenes (Jayaraman et al., 2013, 2015, 2017; Jayaraman & Smith, 2019; Long, Kachergis, et al., 2022; Sugden et al., 2013). In contrast, a lab-based study with object play (~15-20 minutes) did not replicate this decline and instead found a possible U-shaped trajectory, with 12-month-olds seeing slightly fewer faces than 8- or 16-month-olds (Long, Sanchez, et al., 2022). In the current study, we aimed to reconcile these disparities by bridging the gap between less structured home studies and more structured laboratory investigations. To achieve this, we instructed caregivers to record ~1 hour of headcam footage specifically during playtime, but situated within their natural home environments. By strategically constraining certain contextual variables (in this case, type of activity) while preserving the ecological validity of home settings, our approach may provide an opportunity to detect subtler changes in the everyday visual availability of faces across the first years.

Using a cross-sectional developmental trajectory design, we collected egocentric headcam data with the TinyExplorer gear (Nikolov et al., 2024, <https://osf.io/95wvn/>) from 29 young children across the first three years of life (2-30 months). The dataset comprised 1,891 minutes of video (over 5.5 million frames). To process the recordings, we employed the state-of-the-art RetinaFace face-detection algorithm (Deng et al., 2020).

We observed distinct nonlinear changes in face availability across three vertically defined regions of the egocentric video (bottom/middle/top, Figure 1). In early infancy, faces were most common in the middle, with an initial steep decline followed by a modest increase after the first year. In the top region, during the second year, face presence increased and then decreased. The bottom region consistently showed low face presence. These findings suggest that the availability of faces is not only age-dependent but also region-specific, reflecting dynamic reorganisation of everyday visual input. Additionally, face size variability was greater in younger infants, consistent with caregiver-driven interactions. We interpret our findings in the context of emerging motor abilities.

By focusing on a specific activity (playtime), this study demonstrates how nuanced patterns can be detected using shorter recordings than in previous studies - enabling scalability and inclusivity of



naturalistic research. These results offer new insights into early face availability and demonstrate the value of integrating naturalistic methods with automated analysis to advance developmental theory.

Abstract 3, Using Head-Mounted Eye Tracking and Computer Vision to Examine Infant Face Looking During Naturalistic Freeplay

: Gaze plays a central role in early social communication, signaling attention, engagement, and intent (Emery, 2000; Kleinke, 1986). From the first months of life, infants prefer to look at faces in controlled experiments, such as static images or videos of social partners (e.g., Farroni et al., 2005). Yet laboratory studies do not capture how infants encounter and attend to faces during real-world interactions. Recent advances in wearable technology, including head-mounted cameras, provide a more naturalistic view of infants' experiences (Fausey, Jayaraman, & Smith, 2016). However, egocentric scenes from the infant's view are cluttered and infants can only selectively attend to a small proportion of the visual information captured. Consequently, face availability alone cannot explain how and when infants look at faces. Prior studies using head-mounted eye trackers report that infants rarely look at caregivers' faces during play (Franchak, Smith, & Yu, 2024; Yu & Smith, 2013, 2017), but most of this work has been conducted in simplified lab environments.

The present study examined both the visual availability of faces in the first-person view and the real-time dynamics of face looking in a more naturalistic setting. Parents and children ($N = 57$ longitudinal play sessions from 35 dyads; 15 female infants; 12-30 months) played freely with 27 toys while wearing head-mounted eye trackers. The study was conducted in the Home-like Observational Multimodal Environment (HOME) lab, a space designed to resemble a functional apartment with a kitchen area, a living room, and a play area. We combined eye tracking data with computer-vision (RetinaFace) to automatically track caregivers' faces in infants' first-person views and to extract visual properties such as face size and position.

Preliminary results indicate that caregivers' faces were visible only 23 percent of the time, and infants looked at them only 19 percent of that time (Figure 1A-C). Time-series analyses showed that faces typically came into view shortly ($M = 1.19$ s) before infants looked at them, suggesting that infants oriented their heads and bodies to bring the face into view intentionally, rather than looking simply because a face was present. When infants looked at faces, those faces were small in the visual field ($M = 4\%$) but centrally positioned ($M = 16\%$ from center) and infants looked longer at faces that were more centrally located, $b = -2.52$, $SE = 0.47$, $t = -5.24$, $p < .001$. Parent face looks modestly increased the likelihood of an infant face look ($\approx 4\%$ increase; Figure 1D), whereas an infant face look strongly increased the likelihood of a parental face look ($\approx 40\%$), highlighting the bidirectional nature of these interactions. Parental speech and object handling did not significantly predict infant face looking (Figure 1E-G).

These findings highlight the active nature of infant face looking and suggest that it is shaped by both the visual saliency in view and infants' own interest. Next, we will analyze communicative intent to distinguish face looks that serve information-seeking versus information-giving functions, further clarifying how face-directed attention supports early social learning.



Symposium 8.3 - Contingency across contexts: The temporal dynamics of parent-child interaction across lab and home environments in typical and atypical populations

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Summary

Social interactions are prime moments for infant learning. The temporal coordination of infant and caregiver behaviors during social interactions is critical for learning. Our papers address how the temporal dynamics of infant-caregiver interactions shape infant learning and behavior. Paper 1 describes differences in the way toddlers with and without Autism Spectrum Disorder contingently arrange their attention to named objects after instances of repeated object-naming. Paper 2 explores how the predictability of the timing and content of caregiver speech in the home shapes infant vocal behavior. Paper 3 demonstrates bidirectional associations between infant and adult smiling that change with age and adult partner. Paper 4 demonstrates how infants react to changes in their ability to elicit contingent responses in social and non-social contexts. Our discussant will provide an integrative framework for understanding contingency's impact on learning.

Details

Abstract 1, Temporal distribution of caregiver speech affects object attention in TD children but not in children with ASD

Over half of children with autism spectrum disorder (ASD) have language delays (Latreche et al., 2024). Previous work suggests that ASD-related language differences may arise from perceptual input in everyday social interaction (Bianco & Yu, 2025). Children learn new words by mapping object names in caregiver speech to objects in the environment (Yu et al., 2019). One factor that may shape the quality of learning input is the temporal distribution of caregiver speech. Indeed, moments when caregivers name the same object multiple times in quick succession are associated with earlier word acquisition in typically developing (TD) children (Nencheva et al., 2024). We hypothesize that repeated naming extends TD children's attention to the named object, providing richer perceptual input for word learning. We will also conduct exploratory analyses to quantify ASD-related differences in the temporal distribution of naming instances. Further, we will explore whether the relation between repeated naming and child attention differs in relation to ASD diagnosis.

TD toddlers (n=36, Mage=18.8months) and a language-matched group of children with ASD (n=14, Mage=38.1months) and their caregivers played with 24 toys while wearing head-mounted eye-trackers. We annotated child toy fixations and caregiver naming instances, or utterances that included the name of one of the toys. To quantify learning input, we calculated the proportion of time that children spent attending to the named toy (the "target") within 3 seconds of each naming instance onset. Naming instances within 3 seconds of one another were grouped. This yielded three types of instance groups: isolated instances; groups of multiple instances where more than



half involved the same target (“repeated instance groups”); and groups of multiple instances where less than half involved the same target (“non-repeated instance groups”). We calculated the proportion of instances in each type of instance group for each child and the mean target attention for all instances in each group.

Bonferroni-corrected t-tests on the proportion of instance groups in each type revealed that isolated instances were most common in both ASD and TD children. However, in the TD sample, repeated instance groups occurred more frequently than non-repeated instance groups; in the ASD sample, repeated and non-repeated instance groups had similar frequencies (Figure 1). Further, in the TD sample, isolated and repeated instance groups were associated with higher mean target attention than non-repeated instance groups ($p < .01$). However, in the ASD sample, there was no difference in mean target attention across instance group types (Figure 2).

The current work demonstrates ASD-related differences in the temporal distribution of naming instances and their effect on learning input. In TD children, clusters of instances with the same target occur relatively frequently and lead to increased target attention, thereby improving input for learning. In children with ASD, repeated instances are proportionately less common, and the temporal structure of naming instances does not affect learning input. Future work will explore why children with ASD may be less sensitive to the temporal distribution of caregiver naming. This work provides a launch point for the development of interventions to facilitate word learning in day-to-day life.

Abstract 2, Naturalistic moment-to-moment fluctuations in caregiver vocal predictability shape the maturity of infant vocalisations

The association between caregiver unpredictability and developmental outcomes is known (Davis et al., 2022). Examining how fine-grained changes in caregiver predictability influence early infant behaviour may reveal the underlying mechanisms of this relationship. Given the domain-specific effects of caregiver predictability on statistical learning (Forest et al., 2024), we seek to examine how variations in the following micro-dynamics of caregiver vocal predictability modulate infant vocal engagement: temporal predictability (likelihood of contingent responses) and relative response predictability (within-caregiver entropy values of responses). We hypothesise that consistently contingent, high temporal predictability, but variable caregiver responding, lower relative response predictability, exemplifying ‘Goldilocks’ complexity (Kidd et al., 2014), will heighten infant’s attention to the phonological aspects of adult speech (Goldstein and Schwade, 2008), leading to greater production of canonical babbling.

Custom-made wearable devices were used to collect naturalistic, daylong recordings of caregivers and 10-month-old infants interacting at home ($N = 50$). Due to the naturalistic dataset, machine learning-based modelling has been implemented on the dyadic vocal interactions. Caregiver and infant speech were first isolated (Lavechin et al. 2020), then infant-directed caregiver speech was classified in terms of semantic content (e.g declarative, imperative, calling infant name, type of



question, etc.; Esposito et al., 2025), and infant vocalisations in terms of speech maturity (Harvard et al., 2023). To identify temporal predictability, the likelihood of caregivers responding contingently (within 5 seconds), from infant vocalisation offset, was calculated, subtracting the caregiver's baseline vocalisation rate from this, to assign each caregiver with a contingency score. To identify relative response predictability, a sliding window analysis calculated the conditional entropy of the semantic content of contingent responses, given infant non-cry vocalisations, in 30-second windows. Mean-centering these entropy values generates a relative measure of how predictably each caregiver is responding in that temporal window, typical to their own behaviour (Forest et al., 2025). Only periods where the initial infant vocalisation was non-canonical were included in the analysis, to exclude the wrongful interpretation of a canonical burst being influenced by caregiver predictability.

Separating the sample into high contingency and low contingency groups, by a median split, preliminary results show the opposite of our hypothesis, that infants are significantly more likely to producing a canonical vocalisation when caregivers were responding more predictably than their norm, only in the high contingency group (see fig A). These results suggest that when caregivers' responses are consistently timely, infants are sensitive to increases in the predictability of how they respond, in turn producing more mature vocalisations back, than when their caregivers respond less predictably. When overall contingent responding is lower, tracking the timing of responses may outweigh tracking the predictability of the response type.

Further analyses will explore the linguistic predictability (defined as semantic complexity) of contingent responses, investigating whether temporally predictable caregivers modulate the complexity of their speech, contingent on infant states, and the influence this has on infant behaviour. This work aids understanding of how parent-infant interaction systems vary between dyads, and provides another example of how caregiver increased predictability scaffolds infant information-gathering (Forest et al., 2025).

Abstract 3, Infant-adult smiling dynamics: A cross-partner, home-based longitudinal investigation

Social smiling emerges through real-time coordination between infants and adults, yet surprisingly little is known about how infants and adults shape the temporal dynamics of one another's smiling. Fifty-eight infants engaged in face-to-face interactions with their mothers, fathers, and strangers—at 4 and at 8 months (289 total sessions), centering the influence of interactive context in a longitudinal framework. Smiling was reliably coded by human experts as compared to smiling identified by PyAFAR, computer vision software. A multimodel inference framework structured survival analysis of transition rates between four joint smiling states (neither smiling, adult only, infant only, both smiling). There was strong evidence for age and partner effects. We interpret hazard ratios (Figure 1) whose 95% Confidence Intervals do not overlap 1 in the light of cumulative incidence curves (Figure 2). Rows refer to both figures.

Compared to infants, adults initiated smiles at higher rates, terminated smiles at lower rates, and



responded more quickly to their partner's smiles, suggesting that adults act to create and sustain mutual dyadic positivity. When neither partner was smiling (1st row), adults initiated smiles at 7.41 times the infant rate. Similarly, adults reciprocated infant smiles at 2.65 times the rate that infants reciprocated adult smiles (2nd & 3rd rows). Likewise, when both partners were smiling, adults stopped smiling at a tenth the rate of infants.

There was strong evidence for age and partner effects on infant and adult smiling dynamics. Developmentally, eight-month-olds initiated smiles at 1.59 times the rate of 4-month-olds when neither partner was smiling (1st row), suggesting that older infants showed increasing smiling initiative. Adults ended their smiles with 8-month-olds at more than twice the rate they ended their smiles with 4-month-olds (3rd & 4th row), suggesting that infant developmental changes drive interactive reorganization.

Across interaction partners, infants were more likely to engage in mutual smiling with mothers than strangers, suggesting infant selective responsiveness. That is, although strangers initiated smiles at 1.40 times the rate of mothers (1st row) and terminated their smiles at a lower rate than mothers (0.52 when smiling alone, 3rd row; 0.58 when both partners smiling; 4th row), infants reciprocated stranger smiles at 0.78 times the rate they reciprocated mothers' smiles (3rd row). These patterns suggest that while strangers initiated smiles most readily and sustained them longest, mother smiles were most effective at eliciting infant smiles. There were no differences detected between mother and father smiling dynamics.

Results highlight the context-dependent temporal dynamics of the development of infant smiling with diverse adult partners. Overall, there was evidence for bidirectional but asymmetric coordination: Adults provided temporal scaffolding through rapid smiling responses and sustained smiling while infants actively shaped exchanges by ending smiles at higher rates and reciprocating smiles at lower rates than their adult partners. Older infants showed greater propensity to initiate smiling states than younger infants, while adults became more apt to terminate their own smiles with older infants, revealing bidirectional developmental reorganization where each partner's changes scaffold the other's emerging capacities and propensities.

Abstract 4, Social learning is driven by domain-general mechanisms: Infants learn similarly from contingency in social and non-social contexts

We investigated whether domain-general contingency detection abilities support learning from social interactions. Previous research shows that infants produce more advanced sounds as a function of receiving contingent social feedback to their babbling (Goldstein et al., 2003). Furthermore, by 5 months, infants produce vocal extinction bursts in reaction to their caregivers becoming unresponsive, demonstrating expectations for the social efficacy of vocalizing (Elmlinger et al., 2023). Given the importance of contingency in vocal learning, we examined whether 8-11-month-old infants' contingency detection in social and non-social contexts predicted prelinguistic vocal learning.



Methods: 25 infants (7.9 months-10.9 months) came to the laboratory twice. First, infants engaged in a non-social contingency detection task. For two minutes, infants could press a large button to elicit non-social videos of toys and animals. Next, the button became nonfunctional for two minutes. We measured infant pressing rate during both periods. This task was designed as an analog to a still-face paradigm, so a burst in pressing behavior is analogous to a vocal extinction burst. If infants increased their pressing when the button was nonfunctional, we interpreted this as a demonstration of expectations that the button should elicit videos. During the second visit, dyads participated in our vocal learning paradigm, which consisted of four periods. In Baseline 1 (10 minutes), caregivers engaged in typical play with their infants. In Social Response (10 minutes), we asked caregivers to respond to non-cry vocalizations. In No Response (2 minutes), caregivers assumed a neutral face and were unresponsive while their infants freely moved about the playroom. Finally, in Baseline 2 (10 minutes), caregivers returned to their typical play.

Results: Infants displayed an extinction burst in pressing when the button became unresponsive (Figure 1, Panel A). A linear mixed effects model showed a significant increase in pressing rate from Baseline 1 to No Response ($b=9.23$, $p<.001$). In the vocal learning paradigm, infants produced a vocal extinction burst in the No Response period (Figure 1, Panel B). A linear mixed effects model showed a significant increase in vocalization rate from Baseline 1 to No Response ($b=8.288$, $p<.001$). We calculated each infants' percent change in pressing rate and vocalization rate from Baseline 1 to No Response in each task, and ranked infants in descending order from largest to smallest percent change. We found a trending positive correlation between infants' rank in percent change in vocalization rate and pressing rate ($\rho=.041$, $p=.062$) (Figure 2).

Discussion: Infants' related performance in the non-social and social contingency detection tasks points to a domain-general ability to detect the effect of their own behavior on their environments. Our tasks required infants to employ distinct motor behaviors to elicit responses, indicating that contingency detection similarly underlies learning in manual and vocal domains. In contrast to accounts of infant social learning that require prerequisite understanding of other people as agentic or intentional, our findings show that a simple, low-level mechanism of contingency detection drives learning similarly in nonsocial and social domains.

Symposium 8.4 - Community-engaged research focused on infant and perinatal populations

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Summary

Participatory research approaches have gained traction in psychology but remain underutilized in infant and perinatal populations. Community-engaged research (CEnR) approaches position researchers and community members as partners to co-create research questions, methods, and interpretations. This symposium presents four CEnR projects focused on the perinatal/newborn period: a library-partnered study to culturally adapt, scale, and evaluate an empowering early



literacy program for caregivers of newborns; a communication intervention for parents of infants hospitalized in the NICU; a postpartum support program addressing social health; and the adaptation of a preventative perinatal depression intervention for indigenous communities and sexual and gender minority populations. Together, these projects illustrate how centering community wisdom and honoring lived experience can advance inclusive, equitable, and high-impact research on infant development in context.

Details

Abstract 1, Hatchlings - Community-Library Partnerships to Reduce Childhood Literacy Inequities: A Qualitative Investigation: To most effectively address systemic opportunity gaps that lead to disparities in literacy outcomes, researchers, practitioners, and policymakers must invest in supporting school readiness during the perinatal period (Gandhi, 2021; Lindsey et al., 2010; Slaby et al., 2005). Public libraries are a key, free community resource that could be leveraged to address disparities in opportunity, but despite extensive offerings, regions of the U.S. experiencing the greatest material deprivation are also those with the lowest rates of utilization of children's services in libraries (Lopez et al., 2023). The present project aims to address this community-library disconnect and ultimately ameliorate disparities in academic outcomes through a culturally responsive prevention model.

Using a community-engaged research paradigm, university researchers and library staff have formally partnered to culturally adapt, scale up, and evaluate an existing newborn early literacy program ("Hatchlings"). During Hatchlings sessions, librarians share examples of developmentally appropriate learning materials, ways to incorporate language into everyday routines, and songs and rhymes to support early phonological awareness and infant-caregiver attachment. Facilitators discuss infant developmental milestones, emphasize the value of talking, reading, sharing books, and playing for early cognitive and socioemotional development, and assure caregivers that they are capable of supporting their baby's literacy development (Diamant-Cohen). This presentation details the process and rich qualitative findings from the initial focus groups and cultural adaptation, prior to the quantitative evaluation (currently in progress).

The team conducted focus groups or interviews (ngroups = 17, nparticipants = 42) with four key parties relevant to the Hatchlings program: (1) library staff who had previously implemented Hatchlings, (2) community partners who had collaborated with libraries to implement Hatchlings, (3) caregivers who had participated in Hatchlings, and (4) library staff who had not previously implemented Hatchlings. Questions were tailored to the unique context of each of these groups.

The team collaboratively constructed a codebook with 47 codes organized around five major areas: (1) Family Program Adaptations, (2) Program Strengths, (3) Design, Structure, and Content - Expansions and Improvements, (4) Implementation - Expansions and Improvements, and (5) Tensions - Other Barriers, Challenges, or Opportunities. Using a process of inductive thematic analysis, researchers coded each of the transcripts in Dedoose, ultimately yielding 680 excerpts and 1087 code applications. This rich qualitative data was then applied to the existing curriculum



to make it more flexible, context-sensitive, and culturally relevant. Key changes include integrating (1) co-design training to allow librarians to further tailor to local cultural context, (2) essential community resources to support a system of care, and (3) opportunities to facilitate social connectedness among caregivers.

Future directions include a pilot rollout of the new curriculum in 10 library branches across the state. The team will conduct a formal evaluation of the updated program, using interviews, surveys, and daylong audio recordings, as well as publish an open-access, flexible curriculum for librarians and other practitioners to implement. This project was jointly conceived with community partners and is being implemented by researchers and community stakeholders together, so it ideally will yield greater impact due to community buy-in.

Citations:

Diamant-Cohen, B. Hatchlings. Mother Goose on the Loose.
<https://mgol.net/programs/hatchlings/>

Gandhi, J. (2021, February 11). Why I Am No Longer Using the Phrase "Achievement Gap": Perspective from an Educator and Developmental Psychologist. Retrieved from
<https://www.thesocialcreatures.org/thecreaturetimes/opportunity-gap>

Lindsey, R. B., Karns, M. S., & Myatt, K. T. (2010) Culturally proficient education: An asset-based response to conditions of poverty. (1st ed.). Thousand Oaks, CA: Corwin.

Lopez, M. E., Mehra, B., & Capse, M. (2023). An Exploratory Social Justice Framework to Develop Public Library Services with Underserved Families. *Public Library Quarterly*, 42(6), 576–601.
<https://doi.org/10.1080/01616846.2023.2187180>

Slaby, R., Loucks, S., & Stelwagon, P. (2005). Why Is Preschool Essential in Closing the Achievement Gap?. *Educational Leadership and Administration: Teaching and Program Development*, 17, 47-57.

Abstract 2, A Sequential Mixed Methods, Community-Engaged Approach to Enhancing Parent–Infant Communication in the NICU: Infants hospitalized in Neonatal Intensive Care Units (NICUs) face heightened risk for long-term language and cognitive delays due to both biological vulnerability and altered postnatal experiences. Parent–infant interaction is critical for early linguistic and cognitive development, yet the highly technical NICU environment often constrains opportunities for child-directed communication. Many parents feel uncertain about whether or how to communicate with their fragile babies, especially when they are surrounded by complex medical equipment or are sedated. Although early language exposure is a modifiable factor that



supports neurodevelopment, few evidence-based interventions address this domain within the NICU, and existing programs can be too time- or resource-intensive for routine implementation. To address this gap, we used a community-engaged, sequential mixed methods design to understand and enhance parent–infant communication in the NICU.

In the first phase, structured interviews explored beliefs, practices, and barriers surrounding parent–infant communication. Participants (N=40) included multidisciplinary medical staff (physicians, nurses, and other allied health providers) and parents with lived experience caring for infants hospitalized in the NICU. Thematic analysis revealed that while both groups recognized the importance of early language exposure, few understood its neurodevelopmental mechanisms. Participants identified barriers including medical acuity, parental fear, time constraints, and physical obstacles such as incubators and equipment. Both families and staff emphasized the critical role of nurses as coaches and role models and expressed interest in accessible educational resources to support confident, safe, and developmentally meaningful communication. These community insights directly informed the design of a brief, 30-minute, parent-focused education intervention tailored to the realities of the NICU environment.

In the second phase, a randomized controlled trial (N=100 infants across two NICUs) tested the efficacy of the 30-minute educational program delivered at the bedside. The intervention featured short videos and handouts on early brain development and responsive communication, offering parents concrete, developmentally appropriate strategies for talking, reading, and singing to their infants—even when medically fragile. Pre–post measures assessed changes in parents’ knowledge of infant language development and infants’ language exposure during visitation times using Language Environment Analysis (LENA) recorders. Compared to standard care, parents in the intervention exhibited greater increases in knowledge of infant language development, and their infants were exposed to significantly more adult speech during family visits. Moderation analyses revealed that the greatest gains were seen for parents with lower education levels, for fathers (vs. mothers), and for those whose infants were intubated or more medically complex. This suggests that the intervention was most effective for caregivers typically associated with less infant-directed speech and for the most medically at-risk infants, who were notably those of most concern in the qualitative phase.

While future research is needed to determine whether these benefits are sustained beyond discharge and contribute to longer-term developmental outcomes, the present findings demonstrate the impact of a brief, feasible, and community-informed intervention on enhancing parent–infant communication in the NICU. This work underscores the power of integrating diverse professional expertise and lived family experience through community-engaged, mixed methods research to generate practical, scalable solutions that strengthen early developmental experiences for high-risk infants.

Abstract 3, Bonded by Baby: A Community Co-Design Approach to Transforming Postpartum Care: The first year postpartum represents a critical developmental window for infants and a profoundly vulnerable time for caregivers that is too often marked by loneliness, untreated mental health



conditions, and insufficient support from healthcare systems. In the U.S., over 50% of pregnancy-related deaths occur after birth, and mental health conditions are now the leading cause of postpartum mortality, with social isolation or lack of social support contributing to 22% of these deaths in New York State alone. Despite this, few postpartum interventions address social health—the well-being that stems from relationships, belonging, and community—as a primary determinant of parent and infant health and development.

In response, we developed Bonded by Baby | Vinculados por el Bebé, a community co-designed, evidence-based program that embeds social and emotional care into the first year of postpartum care. Rooted in the lived experience of over 1,900 parents, particularly BIPOC, low-income, and immigrant caregivers, the program offers culturally-responsive, trauma-informed group care facilitated by licensed clinicians who reflect the racial, linguistic, and cultural identities of participating families. Cohorts are organized by infant age and geographic proximity to foster peer relationships that endure beyond the program, while the curriculum integrates caregiver mental health support with modules on infant bonding, co-regulation, and early development.

Bonded by Baby is a product of our Social Innovation Lab, a translational research and development model that integrates community co-design and applied science to design, test, and refine social health interventions. Impact evaluation of Bonded by Baby uses validated measures such as the Edinburgh Postnatal Depression Scale, UCLA Loneliness Scale, Parent–Infant Bonding Questionnaire, and Perceived Stress Scale. Early evaluation of the program shows promising results: participants report 29% lower depression ($p < .01$), 21% lower anxiety ($p < .01$), 15% lower stress ($p < .01$), and 20% stronger parent-infant bonding ($p < .01$) compared to control parents.

This presentation will describe Bonded by Baby as a translational bridge between community wisdom and health systems that transforms postpartum care from an individual medical intervention into a relational, family-centered model of healing. We will share our methodology for community co-design, cross-sector integration, and pilot-driven evaluation, and propose a replicable framework for researchers interested in building culturally grounded, systems-embedded programs for improving parent and infant health. We argue that in order to address rising postpartum mental health risks and inequities in infant development, we must treat social health as an essential component alongside physical and mental health.

Abstract 4, Adapting the Mothers and Babies Perinatal Depression Intervention To Expand Its Reach and Impact

: Introduction. The Mothers and Babies (MB) Program is a perinatal depression preventive intervention with demonstrated effectiveness when delivered in a group or individual format. A series of randomized controlled trials demonstrate MB's impact on reducing maternal depressive symptoms (effect sizes from -0.28 to -0.73) and prevention of new cases of major depression. Given the intervention's established effectiveness, recent years have seen our research team engage in several adaptations of MB with the intent of tailoring the intervention to meet the needs of unique perinatal populations. This presentation will describe the framework guiding our adaptations and provide case studies of two specific adaptations.



Hypotheses. We hypothesize that the use of a community-engaged research framework, characterized by the active engagement of community partners, will lead to the development of adapted versions of MB that are deemed feasible and acceptable by MB recipients and service providers.

Study Population. We conducted adaptations of MB for two specific populations. First, we adapted MB for indigenous/tribal communities receiving home visiting services (“Tribal adaptation”). Second, we adapted MB for perinatal sexual and gender minorities (“SGM adaptation”).

Methods. We used the Framework for Reporting Adaptations and Modifications-Expanded (FRAME) to guide our MB adaptations. FRAME consists of eight elements, which were each documented for our Tribal and SGM adaptations; these elements are: (1) when and how during implementation the adaptation was made, (2) whether the adaptation was planned or unplanned, (3) who determined the need for adaptation, (4) what is adapted, (5) at what level of deliver the adaptation occurs, (6) type of nature of content-level adaptations, (7) whether the adaptations are fidelity-consistent with the core intervention, and (8) reasons for the adaptation. Details on the Tribal and SGM adaptations will be presented, providing brief details on each of the above elements. Adaptations were conducted in partnership between the academic research team and community partners. For the Tribal adaptation, we partnered with members of the Lakota tribe in South Dakota, as well as service providers providing home visiting and early childhood services to Lakota families. For the SGM adaptation, we partnered with perinatal SGMs as well as service providers working with this population.

Results. Through a participatory process of engaging with key Tribal and SGM partners, we developed adapted versions of both the Facilitator and Participant Guides for each population. We have recently trained the first cohort of service providers using our MB Tribal Adaptation and are currently completing our SGM Adaptation. Mixed methods data are being collected to understand the perspectives of service providers delivering each adaptation, as well as families receiving the adapted intervention. Findings from these data collection efforts, particularly related to the adapted interventions’ feasibility and acceptability will be provided.

Symposium 8.5 - New horizons for understanding dynamic mother–infant co-regulation: a multimodal and multilayer synchrony approach

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Summary

This multisite symposium advances developmental science’s understanding of mother–infant co-regulation via four multimodal studies.



Paper 1 (Vienna–Potsdam–London) shows that cardiac and respiratory interoceptive sensitivity differentially signal synchrony and the minimal self.

Paper 2 (Tokyo) uses an EEG–ECG model in the Separation–Reunion paradigm, showing that infant regulation is rooted in dyadic, not solitary, physiology.

Paper 3 (Kyoto) adds a longitudinal molecular lens, linking maternal gut microbiota to later child emotion regulation and mapping intervention-relevant microbiota–mood–diet pathways.

Paper 4 (Ramat-Gan) presents a mindfulness-based parental program; increased acceptance, nonreactivity, and focus heighten autonomic synchrony and mitigate mental-health risk.

Using wearable sensors, next-gen sequencing, and integrative analytics, the symposium outlines a multisystem synchrony framework and pinpoints early prevention levers.

Details

Abstract 1. Understanding Mother-Infant Co-regulation: Physiological Synchrony and Interoception at 9 Months

Introduction: The question of how the minimal self, the basic sense of being, develops has been a focus of developmental research for decades. Recent accounts propose that interoceptive sensitivity, the perception of internal bodily signals such as heartbeat or respiration, may constitute one of the earliest forms of a minimal self. Further, some theoretical accounts suggest that interoceptive sensitivity emerges from co-regulation in caregiver–infant interaction, characterized by episodes of interpersonal synchrony (e.g., Fotopoulou & Tsakiris, 2017). Infants, unable to regulate their own bodily signals, such as hunger or stress, rely on their primary caregiver for regulation. Appropriate dyadic interaction then leads to the development of infant’s interoceptive sensitivity and minimal self. In contrast, others have argued that increased infant interoceptive sensitivity may reduce infants’ reliance on co-regulation, leading to lower caregiver–infant interpersonal synchrony. However, empirical evidence on this relationship is currently lacking. Here, we investigate whether 9-month-olds’ cardiac or respiratory interoceptive sensitivity is related to physiological synchrony in caregiver–infant interaction.

Hypotheses: We tested two competing hypotheses: 1) in case infants’ interoceptive sensitivity develops through co-regulation, we expect that infants with higher interoceptive sensitivity will show higher physiological synchrony with their primary caregivers. However, 2) other accounts predict that infants with higher interoceptive sensitivity rely less on co-regulation, in which case we would observe lower physiological synchrony.



Study Population: We tested 90 mother–infant dyads at 9 months; 77 had physiological synchrony data, 52 cardiac interoceptive sensitivity data, and 56 respiratory interoceptive sensitivity data.

Methods: Physiological synchrony was measured during two free-play interactions (without toys, 2:30; with toys, 5:00), for which we computed continuous respiratory sinus arrhythmia (RSA; Abney et al., 2021). We then computed percentage determinism (%DET) in both RSA signals using cross-recurrence quantification analysis, indexing structured, and repeating patterns. Respiratory and cardiac interoceptive sensitivity were measured via two preferential looking paradigms in which infants viewed stimuli pulsating synchronously or asynchronously with their physiological signal (Tünte et al. 2025). Individual differences were quantified as absolute proportional scores indicating the strength of infants' preference for either condition.

Results: Observed %DET values in the with-toys interaction were substantially higher than in shuffled surrogate dyads ($p < .001$). In a preliminary analysis of the with-toys interaction Bayesian beta regressions provided weak evidence for a relationship between %DET and cardiac, but not respiratory, interoceptive sensitivity (Figure 1; cardiac: $\beta = 1.10$, 95% CrI $[-0.10, 2.27]$, BF = 1.58, $N = 32$; respiratory: $\beta = -0.28$, 95% CrI $[-1.47, 0.95]$, BF = 0.34, $N = 37$). Preregistered analyses on the full sample of both interactions, to be presented at ICIS 2026, will further clarify how physiological synchrony relates to the development of infant interoceptive sensitivity. Overall, the preliminary results support theoretical accounts hypothesizing a positive relationship between infant interoceptive sensitivity and physiological synchrony. Further, they suggest that cardiac and respiratory interoceptive sensitivity contribute differently to caregiver–infant physiological synchrony, highlighting the relevance of modality-specific bodily signals for co-regulation and minimal self. Note: Fig 1 in attached file

Abstract 2, Predictive Computational Neurophysiological Markers of Mother–Infant Interaction

Introduction. Mother–infant interactions are a key context for the emergence of early emotion-regulation capacities. The Still-Face Paradigm (SFP) provides a controlled perturbation to probe these dynamics, capturing how infants physiologically reorganize in response to caregiver withdrawal. However, isolating meaningful regulatory markers is challenging, as they must be extracted from dynamically coupled, multimodal, and phase-dependent physiological signals. To address this, we propose a context-aware, multimodal computational framework to systematically characterize infants' neurophysiological regulatory patterns under mild social stress.

Materials. We analyzed EEG and ECG signals recorded simultaneously from 64 Japanese mother–infant dyads (infants: $M=236$ days; mothers: $M=33.3$ years) across the SFP phases: free-play (FP), still-face (SF), reunion (RU). Infant behavior was manually annotated frame by frame and assigned distress scores to quantify regulatory responses throughout the interaction. We extracted theta- and alpha-band power spectral density (PSD) from frontal (left and right), central, and parietal EEG regions, and derived R–R intervals (RRI) and heart rate variability (HRV) from ECG signals. Behaviorally, k-means clustering of distress trajectories identified three behavioral categories: recovery infants ($N=19$) showed a clear increase in distress from FP to SF followed by a marked reduction during RU; no-recovery infants ($N=19$) maintained high distress into RU; and low-variance infants ($N=20$) displayed consistently similar distress across the three phases.



Methodology. Figure 1 shows our computational framework that integrates mother and infant EEG and ECG features across the SFP in a phase-organized manner to predict infants' behavioral categories and identify the features most predictive of infant behavior.

The model first encodes infant and mother neurophysiological activity separately. To quantify how infants' signals track concurrent mothers' signals, highlighting mother patterns most informative for the infant, we applied cross-attention mechanism. Then a contrastive learning module aligns infants' internal neurophysiological states with their phase-specific responses and injects mother–infant interaction information into the infant representation space. The resulting phase-organized representations support end-to-end prediction of the three behavioral categories, providing a computationally precise characterization of how dyadic physiological coupling underlies emerging regulatory outcomes.

To identify the features most relevant to these categories, we computed a Unified Ranking Score that combines each feature's predictive contribution, separation among categories, and stability into a global importance ranking.

Results. Our framework classified behavioral categories with an accuracy of 0.7656 ± 0.0492 and a F1 score of 0.7688 ± 0.0533 . The Unified Ranking Score (Fig. 2d) revealed a clear hierarchy of multimodal markers: cardiac indicators were substantially more predictive than cortical EEG features. Infant RRI during FP ranked highest followed by RRI during SF and HRV during FP. Crucially, although the behavioral difference between recovery and no-recovery infants emerges only in the RU phase, it is prospectively captured by neurophysiological signals from the earlier FP and SF phases. Accordingly, the dyad's pre-RU physiological state provides the primary explanatory signal for RU outcomes. Viewed this way, infant regulation emerges from the mother–infant relational system rather than from infants' isolated responses during the RU episode.

Abstract 3, Supporting the Developing Microbiota–Gut–Brain Axis in the Mother–Child Dyad: Associations with Emotion Regulation and Mental Health

The microbiota–gut–brain axis has gained increasing attention as evidence accumulates linking gut microbiota to autonomic, immune, and prefrontal–limbic functioning. Gut microbiota are largely transmitted from mothers to their children at birth and undergo rapid maturation, reaching an adult-like profile by ages 3–5—an important period for prefrontal cortical development. Clarifying how gut microbiota relate to mental health and factors such as lifestyle and dietary habits is essential for supporting maternal and child well-being. This symposium presents two studies: Study 1 longitudinally examines how gut microbiota composition relates to emotion regulation and later mental health risk in children aged 3–5 years, and Study 2 examines relationships among maternal gut microbiota, mental health, and dietary habits.

We have been collecting data on gut microbiota and psychological and cognitive development from a large, community-based subclinical cohort of more than 2,500 mother–child pairs in Japan. As part of this project, Study 1 analyzed 257 children aged 3–4 years, 68 of whom completed follow-up at age 5 (mean = 66.9 months, SD = 3.2 months). Emotion regulation was assessed using the Behavior Rating Inventory of Executive Function–Preschool Version and problem behaviors using the Child Behavior Checklist. Study 2 analyzed 344 mothers of children aged 0–4 years (mean



age = 34.63, SD = 4.78, range: 21–47 years). Maternal depression, somatic symptoms, and dietary habits were evaluated using the Beck Depression Inventory-II, the Multidimensional Physical Symptoms scale, and a self-administered questionnaire. In both studies, gut microbiota were assessed via stool samples and 16S rRNA sequencing to evaluate microbial diversity and the relative abundance of genera.

Study 1 revealed that a higher relative abundance of *Coprobacillus* at age 3 was related to increased risks of externalizing (mediation effect = 0.13, 95% CI [0.02, 1.09]) and internalizing (mediation effect = -0.07, 95% CI [-0.63, -0.01]) problem behaviors at age 5 via lower Inhibitory Self-Control. Because *Coprobacillus* has been linked to increased IL-17—which affects cortical development and induces autism-like behaviors in mice—these findings suggest that early inflammatory gut environments may heighten vulnerability in emotion regulation and later mental health. Study 2 showed that lower microbiota diversity and reduced abundance of butyrate-producing genera (e.g., *Lachnospira*, *Faecalibacterium*, *Subdoligranulum*) were associated with higher depressive mood (p 's < .05, q 's < .10). A diet rich in soy products, fermented foods, seaweed, mushrooms, and vegetables was linked to better mental and physical health and favorable microbiota profiles, including higher levels of *Lachnospira*, *Agathobacter*, and *Subdoligranulum*. Because these genera are butyrate producers that help maintain a healthy gut environment, their reduction may contribute to dysbiosis associated with poorer maternal health. Traditional Japanese foods rich in fermentable substrates and fermented products may help support these beneficial microbes and act like probiotics. We will discuss the importance of supporting the microbiota–gut–brain axis in both mothers and children, and the need for personalized, daily-life–based interventions tailored to individual gut microbiota profiles.

Abstract 4, Enhancing Mindful Parenting and Dyadic Synchrony: Pioneering data from the Integrative Mindfulness-Based Infant Parenting Program

Background. Parenting during infancy places continuous demands on caregivers' emotion regulation, particularly in high-risk contexts such as preterm birth, underscoring the need for interventions that cultivate parent–child co-regulation, for which mindfulness is a promising yet rarely applied approach. The Integrative Mindfulness-Based Infant Parenting Program (IMIP; Burstein et al., 2025) is an 8-week group intervention grounded in a mindfulness framework integrating trauma-informed, emotion-focused, and validation-based strategies to nurture non-judgmental acceptance of one's parenting, attuned engagement with the infant, and dyadic synchrony. This feasibility study evaluated IMIP's acceptability and preliminary efficacy and whether gains in mindful parenting are linked with changes in parental focused attention (FA), caregiver distress, infant exploration, and parent–infant autonomic synchrony.

Methods. Thirty-two caregivers of preterm and full-term infants (corrected infant age 3–24 months) completed pre- and post-intervention assessments, with IMIP delivered in two versions (standard full-term and preterm-adapted). At each visit, dyads participated in (a) a semi-structured “table play” task with concurrent caregiver and infant ECG recording and (b) a naturalistic free-play interaction. Behavioral coding yielded indices of parental FA, orienting, and infant' focused-exploration. Caregivers completed self-report measures of mindful parenting, parenting confidence, depressive symptoms, and parenting stress. Caregiver–infant autonomic synchrony was indexed via cross-correlations of heart-rate time series. Mixed-effects models tested pre/post



and group (preterm/full-term) effects; change-score correlations probed links between mindfulness facets and behavioral/physiological outcomes.

Results. IMIP was feasible and well tolerated (attrition rate 5.9%). Parental FA increased in both free play ($b = 0.08, p = .005$) and table play ($b = 0.17, p < .001$), whereas looking/orienting did not change, supporting the specificity of a mindful-attention effect. Gains in parental FA were associated with increases in infant focused-exploration. Self-reported mindful parenting improved at the total-scale level ($b = 10.75, p < .001$) and across subscales, with most gains in non-judgmental acceptance; greater increases in acceptance and emotional non-reactivity were associated with higher parenting confidence, reduced depressive symptoms, and lower parenting stress. Caregiver–infant autonomic synchrony strengthened from pre- to post-intervention in both peak ($b = 0.17, p = .041$) and concurrent ($b = 0.20, p = .036$) heart-rate coupling and was positively associated with both parental and infant FA, suggesting a physiological pathway by which mindful caregiving may scaffold infant exploration. Caregivers with elevated baseline depressive symptoms showed especially pronounced reductions, such that post-intervention depression scores no longer differed from non-depressed peers. Effects were broadly comparable for preterm and full-term families.

Conclusions. Findings indicate that an infancy-focused, mindfulness-based parenting program is feasible and may promote multilevel gains in mindful caregiving, caregiver well-being, infant exploratory behavior, and, critically, dynamic caregiver–infant autonomic synchrony in preterm and full-term contexts. By foregrounding non-judgmental acceptance and in-the-moment, non-reactive attention to the infant, IMIP appears to enhance regulatory mechanisms through which caregivers stabilize their own arousal and more effectively co-regulate with their child. Pending replication in randomized controlled trials with longer follow-up, these results highlight parental acceptance, emotional non-reactivity, FA, and autonomic synchrony as key pathways by which mindfulness-based interventions may support early co-regulation.

Symposium 8.6 - Development of memory encoding, consolidation, and retrieval in infants: context factors and methodological insights

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Summary

Infant memory develops rapidly. Understanding its trajectory requires a contextual perspective, going beyond the study of specific skills in isolation with a single method (Oakes, 2009). This symposium brings together scientists studying infant memory using diverse methods in controlled designs to understand factors shaping encoding, consolidation and retrieval. Talk 1 shows that 18-24-month-olds remember complex object-context-place associations after 6 months and discusses multiple sources of individual differences. Talk 2 presents converging behavioral and neural evidence for context memory in 18-23-month-olds. Talk 3 discusses a longitudinal study of memory consolidation and how this varies over wake and sleep intervals in 9-15-month-olds. Talk 4 reveals diverging, method-dependent, effects of sleep on memory in 15-24-month-olds. The



discussant will summarize these findings and consider how diverging findings can guide future research on infant memory in context.

Details

Abstract 1, Title: Forgotten beginnings: Studying infantile amnesia in toddlers through a naturalistic learning paradigm

Introduction:

Why do we forget our earliest memories from childhood? Despite children's remarkable learning abilities, they are unable to retain memories formed in the first two to three years of life - a phenomenon known as infantile amnesia (IA). This pervasive yet understudied form of forgetting extends across several mammalian species, including rodents. However, the causes, duration, and precise endpoint of IA in humans remain unclear. Traditionally thought to affect all individuals uniformly, recent animal studies suggest that early memories may not be permanently lost but rather inaccessible, and that susceptibility to IA may vary under certain developmental conditions. Translating these mechanistic insights to humans requires prospective, systematic investigations of how early memories are encoded, retained, and ultimately forgotten under controlled but naturalistic conditions.

Hypotheses:

Toddlers, even as young as 18-20 months, are capable of encoding and retrieving complex object-place-context associations. However, there are large interindividual differences in learning and maintaining such complex object-place-context associations among toddlers.

Study Population:

The study includes 400 toddlers aged 18–24 months.

Methods:

This study applies a naturalistic, immersive hide-and-seek paradigm, developed as a human analogue of the rodent Barnes maze, to examine long-term memory retention in toddlers. In a 4 × 4 m arena enriched with distinctive contextual cues, toddlers learned the location of a hidden toy relative to their environment, enabling the assessment of object memory, contextual binding, and object-place-context integration. Following initial learning, all participants completed a 24-hour recall session, providing a short-delay benchmark. They were then assigned to long-term retention tests at 1, 3, or 6 months, permitting analysis of memory retention across intervals that capture the developmental window in which IA is thought to occur. To probe the origins of inter-individual variability in memory formation and maintenance, ongoing analyses incorporates (i) markerless pose estimation using DeepLabCut, (ii) trajectory-based profiling of variability in search strategies, (iii) mobile EEG to analyze neural correlates of memory encoding and retention and (iv) language assessment to measures how language development might support or constrain long-term retention.

Results: Findings show that toddlers successfully encode and retain complex object-place-context associations, demonstrating robust memory expression after the initial learning phase and at the 24-hour recall session. Critically, toddlers continue to retain these associations even after



long-term delays of up to 6 months. Across the full 18–24-month age range, retention remains strong, with no reliable effects of age at encoding or delay duration. Instead, substantial individual differences emerge, suggesting that early memory formation and maintenance is far from uniform and may be shaped by factors beyond age alone.

Conclusion:

Together, these findings challenge traditional assumptions about infantile amnesia by demonstrating that toddlers can form and retain rich object–place–context associations over substantial delays, even up to six months. The absence of age-related differences suggests that the expression of IA is not determined solely by chronological maturation, pointing instead to meaningful inter-individual variability in how early memories are retained.

Abstract 2, Title: Infant hippocampus retains context-specific episodic information

Introduction: Infants can form memories for unique events, but often fail to main events for long periods of time and discriminate between similar events without added cues (Newcombe et al., 2014). We seek to determine whether tasks leveraging eye-movements to provide an index of context discrimination as well as neuroimaging approaches can help determine whether infants retain context-specific information beyond initial learning.

Study Population: We used functional neuroimaging and behavioral tasks to assess 27 infants 18- to 23-months of age.

Methods: Two similar, but decorated differently, laboratory rooms established unique contexts (Room A and Room B). Inside each room, infants played with a block with an animate face paired with a song. They then completed two word learning memory games. After completing both Room A and Room B, infants viewed a visual paired comparison task to assess memory discrimination. Trials consisted of images of target items (e.g., faces, word learning objects) paired to the associated learned songs or words with distractors originating from either the same context or the opposing context. The same procedure was repeated a second time, one week later. After the second behavioral visit, infants completed a block design fMRI task with both novel and learned words and songs.

Results: Infants showed a visual preference for audio-paired stimuli when the distractor came from the opposing context ($t = 2.55$; $p < .01$), indicative of successful context discrimination, even in children as young as 18-months. Consistently, hippocampal activity in the blocked design was greater for learned compared to novel stimuli, and prior visual preference for remembered stimuli predicted said activation ($r = .45$, $p = .02$), linking behavioral discrimination and neural evidence of memory. Multivariate patterns of hippocampal activity displayed highly dissimilar activation patterns between stimuli learned in different contexts. Specifically, Representational Similarity Analyses (RSA) revealed that stimuli learned in the same context evoked more similar hippocampal patterns to each other than stimuli learned in different rooms, underscoring context discrimination abilities in the infant hippocampus. Finally, infants' RSA matrices corresponded more strongly with a model emphasizing context (i.e., events learned in Room A vs Room B) than a model representing stimuli type (i.e., song vs word stimuli; $t = 11.77$, $p < .001$).



Conclusion: The presence of context-specific representations in the hippocampus suggests that this structure can support episodic consolidation as early as 18-months of age and that other non-encoding mechanisms may be responsible for rapid forgetting in the first few years of life.

Abstract 3, Title: Longitudinal changes in memory consolidation over morning and afternoon naps in infants

Introduction: Prior work has shown that as children transition from a biphasic sleep pattern (one nap per day) to a monophasic sleep pattern (just overnight sleep), naps remain protective of memories. What changes across this transition is how catastrophic wake during a typical naptime is to memory: for habitual nappers, not napping causes substantial forgetting of recent memories while for non-habitual nappers, memories do not suffer without a nap. This is thought to reflect a more mature hippocampus in non-habitual nappers, reducing both the need to consolidate memories as frequently and the effects of memory interference.

Hypotheses: Infants transition from a triphasic (a morning and afternoon nap) to a biphasic (one afternoon nap) sleep pattern between 9-15 months. As the morning nap becomes less essential, we hypothesize skipping it may be less detrimental to memories; they can now hold more memories until the afternoon nap. Moreover, given that daytime sleep is consolidated into a longer afternoon nap, we predict that the memory function of the afternoon nap is maintained across this developmental period.

Study population: Parent-infant dyads were recruited and scheduled for their first wave of data collection when the infant was 9 months with subsequent waves at 12 and 15 months. To date, the sample includes 78 infants (36 females, 42 males). The sample is predominately white (80%) with 5% Black or African American, 3% Asian, and 12% reporting more than one race. 14% is Hispanic or Latino.

Methods: Infants were tested twice at each wave. In one visit, they took both a morning and afternoon nap. In the other, they were kept awake during one of the nap intervals. Infants were randomly assigned to either the morning nap manipulation or afternoon nap manipulation, indicating which nap was skipped. The deferred imitation task was used to assess memory. Before nap or wake intervals, infants were presented with the deferred imitation objects, and immediate recall was assessed. Memory was assessed again after a nap or wake interval. Nap physiology was recorded using polysomnography.

Results: We compared the change in memory across nap and wake intervals. Surprisingly, so far, there is no benefit of the nap on deferred imitation learning over morning or afternoon naps (no significant main effect interval type; morning: $p=.132$, afternoon: $p=.409$). In the morning nap manipulation group, the interaction of interval type and age (9, 12, or 15 months) was also not significant ($p=.108$). Likewise, in the afternoon nap manipulation group, the interaction of interval type and age was not significant ($p=.700$).

Conclusion: Based on half of our planned sample, these data suggest that neither morning nor afternoon naps are beneficial for deferred imitation learning. It is possible that there is a small effect that is not yet clear due to the low number of trials in each condition and a larger sample may



make differences clearer. These results will also be discussed in the context of changes on nap physiology.

Abstract 4, Title: The effect of napping on selective memory consolidation in infants

Introduction: Given the wealth of new information they encounter every day, infants face the challenge of selecting only some of this information for long-term retention. Post-encoding sleep facilitates memory consolidation in infants. Initial evidence suggests this support may preferentially target information perceived as relevant for future use (Konrad et al., 2019). Here, we present findings of two experiments investigating the effects of napping on selective memory consolidation in infants, specifically addressing the context of digital media learning, scaffolding and the retention of unexpected events.

The first experiment investigated memory using two deferred imitation tasks, comparing live and video demonstrations (Hermesch et al., 2025).

Study population: N=68 15- and 24-month-olds in the live and N=69 in the video condition.

Methods: Infants watched demonstrations of the two tasks (live or on prerecorded video), one with caregiver scaffolding. Infants in the nap condition then took a nap (>30 mins), while infants in the wake condition stayed awake in the following 4 hours. Memory for the target actions was tested 24-hours later.

Results: Analysis showed that infants who had napped retrieved more target actions than those who had been awake. Infants' memory performance after a live demonstration was better than after a video demonstration, showing a significant transfer deficit (i.e. difficulty learning from screens). Unexpectedly, a cross-experiment comparison revealed that caregiver scaffolding had a disruptive effect on memory performance in 15-month-olds. At these ages, scaffolding that lacks relevance or is too complex may increase cognitive load and interfere with memory encoding rather than support it.

The second experiment assessed if post-encoding naps selectively strengthen memories related to unexpected events.

Study population: N=34 18-month-olds assigned to nap or wake condition

Methods: Infants observed televised events violating or agreeing with physical principles (e.g., an object passing through a wall) and learned an object-color association. Infants were assigned to pre-nap or post-nap encoding. Recognition memory was assessed after 24 hours via preferential looking and exploration.

Results: Infants in the nap condition failed to show recognition memory of the visual association. Only awake infants preferentially explored the object from the event that violated expectations. This suggests violation information is salient enough to be retained through wakefulness and potentially consolidated later. However, a control study showed infants participating before a nap (after prolonged wakefulness) did not encode the Violation-of-Expectation (VoE) event context, implying VoE encoding is susceptible to prolonged wakefulness. Consequently, the study could not



definitively conclude on the selective nap effect for VoE memories, stressing the need to verify robust encoding prior to sleep.

Conclusion: These two studies highlight the complex and context-dependent nature of memory consolidation in infants. Experiment 1 reinforced the cognitive load of digital learning and revealed that, for younger infants, caregiver scaffolding may interfere with consolidation if it adds to the load. Experiment 2 demonstrated that encoding itself is vulnerable, particularly for salient, unexpected information (VoE) after prolonged wakefulness, making sleep effects challenging to assess. Future research should consider robust encoding verification to isolate the differential effect of napping on infant memories.