Hand-Eye Coordination and Visual Attention in Infancy

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Objectives

Infants select objects for visual attention by directing their gaze, and they often do so in very crowded and cluttered environments. Visual clutter can be reduced by using manual actions to bring objects closer to the head and eyes, providing optimal moments for learning and exploration. The alignment of manual actions and gaze, hand-eye coordination, is therefore hypothesized to be an important ability for controlling and distributing attention. However, for infants, this ability to integrate manual actions and gaze to control nearby objects is just starting to develop. Little is known about how hand-eye coordination impacts attention in environments with many possible objects to select. Here, we present a study investigating the extent to which hand-eye coordination impacts the distribution of visual attention in cluttered environments.

Methods

Twenty-five infants (M=19.4 months, SD=2.17 months) and their parents participated in a 10-minute naturalistic toy play session. Each play session was unconstrained and included 24 toys. Video and head-mounted eye-tracking were used to collect manual actions and eye gaze, respectively. Manual actions on and gaze to objects by infants were recorded and coded. Hand-eye coordination was derived by measuring the proportion of frames that included manual action and gaze on the same toy. A median split was conducted on the proportion of time in hand-eye coordination to partition infants into either the 'low' hand-eye coordination group or the 'high' hand-eye coordination ability group.

Results

Overall, the high group (M=0.76, SD=0.29) had a higher proportion of toy looks relative to the low group (M=0.60, SD=0.18), p<.001. To determine differences in the distributions of visual attention across the two groups, rank-ordered cumulative functions of toy-specific look proportions were submitted to growth curve analyses (see Figure 1). For the high group, there were no differences in the shapes of the cumulative functions of toy looks when infants just looked at objects and when they both looked at and held objects, ps>.1. However, for the low group, there were differences in the shapes of the cumulative functions of toy looks when infants just looked at objects and when they both looked at and held objects (intercept, linear, and quadratic coefficients: ps<.001). These results suggest that when the infants with low hand-eye coordination looked at and held toys, their visual attention was disrupted.

Discussion/Conclusion

Our findings indicate that individual differences in hand-eye coordination impact the extent to which infants distribute their visual attention in a cluttered environment. A typical distribution of visual attention to objects in a cluttered environment is highly right-skewed, indicative of

selectivity of visual attention. Infants with low hand-eye coordination abilities had overall lower proportions of visual attention to toys and when they looked at and held toys, showed lower selectivity and a disrupted distribution of visual attention. These results suggest that during the second year of life, there is high variability in the ability to integrate both gaze and manual actions onto objects and this ability has important consequences for the visual experiences of infants.

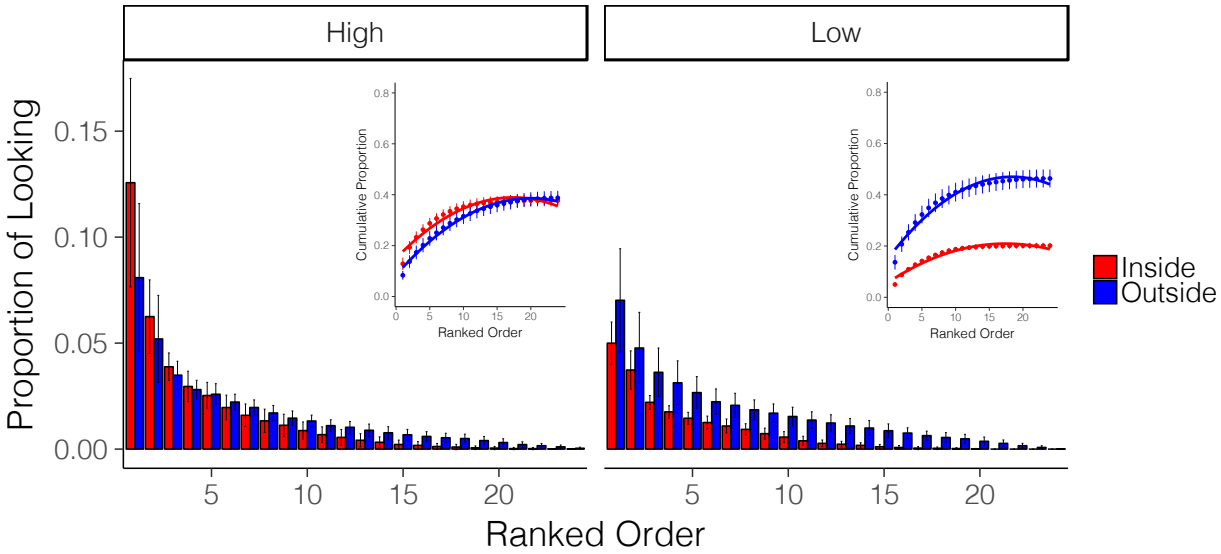

Figure 1. Ranked order histograms of toy look proportions inside (red) and outside (blue) of hand-eye coordination for the High (left) and Low (right) hand-eye coordination groups. Error bars indicate 95% confidence intervals. Inset. Growth curve models of ranked order toy look cumulative proportions. Solid lines represent quadratic fit estimates. Error bars indicate 95% confidence intervals.

Author Identification – Name and place of work

Meirav Arieli-Attali, Lu Ou, Vanessa Simmering, ACTNext by ACT

Title

Modelling the Dynamics of Choice in Self-Adapted Testing under Learning versus Performance Goals

Abstract (500 words)

Self-adapted testing is designed to allow examinees to choose the level of difficulty of the items they complete. Using Item Response Theory modelling, examinees' ability can be estimated regardless of the items chosen. However, the difficulty preferences may be an indication of examinees metacognitive and/or motivational state. To this end, we compared examinees' choices across instructional conditions, termed "performance" versus "learning" goals (Dweck & Leggett 1988). These correspond respectively to "fixed" versus "growth" mindset (Dweck, 2006), a well-established distinction between attitudes towards performing tasks. Performance goals lead individuals to focus on maximizing results (scores), whereas learning goals drive individuals to make more exploratory and challenging choices.

We are conducting a secondary analysis on data collected previously (Arieli-Attali, 2015), where goal was manipulated between groups, and examinees' choices of difficulty, correctness, and confidence were recorded on each item. 583 participants took a 40-item self-adapted test of open-ended general knowledge items, and were instructed either to maximize their score (performance condition) or to use the test as a learning tool for a future test (learning condition). Arieli-Attali found that the learning group chose more difficult items – both initially and across items – than the performance group. Our secondary analyses aim to address how the difference between groups were exhibited in the *dynamics of choices* and related to correctness and confidence.

We modeled examinees' choices of item difficulty using a Hidden Markov Model (HMM), where in each regime examinees choose items that fall under one of the latent states of item difficulty level, and transitions between regimes depend on the condition, accumulated correctness and confidence, and interactions therein. Analyses indicated that a 3-state HMM (low, medium, high) provided the best fit. With examinees pre-test scores controlled, the log-odds of starting with medium- or high-difficulty items, compared to low-difficulty, was larger in the learning-based condition, than in the performance-based condition. Within a condition, higher pre-test scores corresponded to higher likelihood of initially choosing medium or high difficulty compared to low.

For transition probabilities across items, a model with only condition as a predictor showed more likelihood of upward transitions under learning versus performance goals. Adding accumulated correctness and confidence to the model showed interactions with condition. With low confidence and correctness ("don't know"), examinees in the performance condition were more likely to continue in low or medium difficulty, relative to the learning condition. With high confidence and correctness ("know") the groups showed little difference in transitions and tended to stay in the same level. With low confidence and high correctness ("lucky guess"), the performance condition showed more likelihood of upward transitions from low difficulty relative to the learning condition. With high confidence and low

correctness (“slips”), examinees in the performance condition were more likely to continue in medium or high difficulty, or to transition upward from low difficulty.

These results indicate that the dynamics of examinees’ difficulty choices varied with goals, confidence, and correctness. We hope this study will provide insights on how to monitor and promote growth mindset in self-adapted learning environments and assessments.

TITLE: Toddlers Modulate Oscillation Frequency and Amplitude Ratio when Learning a New Bimanual Coordination Pattern

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OBJECTIVE:

The aim of this project is to apply the Haken-Kelso-Bunz (HKB; 1985) model of oscillatory bimanual coordination to study the emergence of the anti-phase pattern of coordination. Specifically, we examined whether toddlers modulated different parameters of their movement to decrease the competition between intrinsic dynamics and the to-be-learned pattern as they performed a modeled drumming task. The bimanual oscillation paradigm has been frequently used to assess the short-term dynamics of coordinative actions in older children and adults, but, to date, has not been extended into developmental analysis of infants and toddlers who are just learning to produce the anti-phase coordination pattern. The specific objective of the analyses reported in this presentation is to report the extent to which toddlers modulate oscillation frequency and amplitude ratio within and across practice sessions to effect shifts in relative phase.

METHODS:

We conducted a longitudinal study in which eight toddlers 15-27 months of age were video recorded as they engaged monthly in a bimanual task using drumsticks to strike a small drum. An adult model demonstrated in-phase, anti-phase, or no drumming in different bouts within each session. Drumming bouts were isolated and digitized using Vicon/Peak Motus software.

The vertical motion of the drumsticks over time served as the basis for analysis of relative phase, oscillation frequency, and oscillation amplitude ratio in each participant.

RESULTS:

We examined microgenetic and ontogenetic emergence and stability of the children's use of anti-phase coordination within a dynamical systems framework. We observed that toddlers presented isolated cycles with relative phases around the anti-phase pattern as early as 15-17 months of age but more stable patterns were more likely to occur later, around the 20th month of age. This development was observed through an increase in the length of sequential anti-phase cycles performed, primarily in the anti-phase model condition. A linear mixed effect model showed that oscillation frequency was inversely related to relative phase (estimate: -7.58, t (7361) = 14.83, $p < .001$). In other words, anti-phase bouts were performed at lower frequencies than in-phase bouts; on average, half of the toddlers appeared to explore lower oscillation frequencies in order to modulate relative phase. Also, a χ^2 test showed that, for six participants (p's < .050), modulation of the amplitude ratio between limbs resulted in shifts from in-phase to anti-phase.

CONCLUSION/DISCUSSION:

Our findings suggest that toddlers differentially exploit slowing oscillation frequency and adjusting movement amplitude of one or both limbs to support phase-shifts to anti-phase action during drumming bouts. Modulation of these two parameters occurs within trials or across months, suggesting the complex interplay of constraints when learning the new coordination pattern. In light of these results, we present a discussion of some of the primary constraints at

play during this period of development and provide a conceptual extension of the HKB model that would fit our observations.

Processes of Learning from Competent and Incompetent Models

Julia Brehm, Anja Gampe, Moritz M. Daum

Us humans are social learners. We continuously acquire novel information from the people around us. To be able to filter incoming information based on their truth value, we must be able to judge whether someone is likely to give correct or incorrect information. We can judge whether people are trustworthy based on prior experiences, among other factors. This mechanism of trust develops early in life: Already at 14 months, children selectively learn from competent others and not from incompetent others. However, to date, little is known about how the ability to discriminate between differently competent model translates to selective learning. Especially, cognitive processes underlying this phenomenon are still hardly understood. One reason for reduced learning from incompetent models might be, that novel information coming from these models is processed differently during a learning phase as compared to novel information coming from a competent model.

To investigate this open question, we conducted a combined behavioral and eye-tracking study in children at four years of age. Children were assigned to one of four conditions in which they were familiarized with an either competent or incompetent model in one of two domains (action of language). Afterwards all children were taught novel actions (four-step action sequence) from the model. To assess differences in processing of information during learning from different models, we applied recurrence quantification analysis to eye-tracking data collected during this action teaching phase. Learning outcome was assessed by calculating the number of correctly imitated action steps. Processes of learning were assessed via the recurrence rate of fixation patterns to action relevant areas of interest. We calculated an ordinary least squares model with the imitation score as dependent variable and recurrence rate and condition, as well as the interaction of the two, as predictors. Preliminary data from 38 children suggest that the model fitted the data (estimate = 4.4697, *SE* = 1.525, p = 0.006). The recurrence rate was a marginal significant predictor of the learning outcome (estimate = -25.8635, *SE* = 13.954, p = 0.072). Furthermore, the interaction between the recurrence rate and condition approached significance (estimate = 10.5879, *SE* = 5.560, p = 0.065).

The results suggest that the looking pattern during learning might be associated to the learning outcome and that this association might be of different quality in the different conditions. Currently the limited data does not allow us to draw strong conclusions.

However, we are adding more data to investigate these effects further and to understand more about the way children are processing novel information depending on the models' competence.

Ryan A. Cannistraci, Jessica F. Hay, & Aaron T. Buss
University of Tennessee, Knoxville

Title: A Dynamic Field Theory Account of Audiovisual Speech Perception: Explaining the McGurk Effect and Perception of Incongruous Audiovisual Stimuli

Objectives: The objective of the Dynamic Field Theory model presented here was to simulate canonical audiovisual integration effects in speech perception, known as the McGurk effect (McGurk & MacDonald, 1976). The classic McGurk effect is created by temporally syncing presentations of an auditory /ba/ stimulus and a visual /ga/ stimulus, which is typically perceived as a fused /da/ or /tha/ percept, and there has been recent interest in modeling its underlying dynamics (Magnotti & Beauchamp, 2017). While this fusion effect has garnered much attention, demonstrations of visually dominant effects (e.g., auditory /ba/, visual /va/) and auditory dominant effects (e.g., /auditory /ba/, visual /ga/) are also present in the extant literature. Here, we constructed a dynamic neural field model to simulate congruent audiovisual speech as well as incongruent speech that leads to visually dominant effects, auditory dominant effects, and perceptual fusion effects (the classic McGurk effect) using the same architecture and parameters across stimulus combinations.

Methods: A three-layer, feature integration Dynamic Field Theory model was constructed using the COSIVINA framework (Schöner & Spencer, 2015). The model is composed of an excitatory phoneme field which is coupled to two-dimensional excitatory fields that bind auditory and visual sensory stimuli with phonemes. The visual field was implemented to represent place of articulation and the auditory field was implemented to represent voice onset time. The model included 5 syllable combinations across all three fields (/*ba*/, /*va*/, /*tha*/, /*da*/, & /*ga*/) that are implemented through pre-shaping inputs that associate features with phonemes. We simulated four effects: 1) Audiovisual congruence (auditory /*ba*/, visual /*ba*/), 2) visual-dominant percepts (auditory /*ba*/, visual /*va*/), 3) fusion percepts (i.e., the McGurk effect: auditory /*ba*/, visual /*ga*/), and 4) auditory-dominant percepts (auditory /*ga*/, visual /*ba*/).

Results: Our initial simulation results demonstrated that the model produces behavior consistent with congruent audiovisual speech (100% /*ba*/), canonical McGurk effects (100% /*da*/, McGurk & MacDonald, 1976), and auditory dominance effects (100% /*ga*/, Magnotti & Beauchamp, 2017). Additionally, the model simulated visual dominance effects on 52% of trials. Although, infants do appear to show visual dominance effects using auditory /*ba*/ and visual /*va/* stimuli (Rosenblum et al., 1997), we do not yet have behavioral data from adults for comparison with our model.

Discussion: These simulation results illustrate how a complex pattern of responses across different stimuli configurations can arise from common neural dynamics involved in binding information across sensory modalities. Future work will be expanded in three directions. We are currently simulating predicted hemodynamic responses for each of the above conditions which we will test using fNIRS from infancy to adulthood. Additionally, the model will be given incongruent audiovisual speech combinations that have not yet been tested to create a new set of behavioral predictions for future exploration. Finally, since the McGurk effect has been demonstrated in infant participants as young as 4.5-months and has been suggested to strengthen across the lifespan, we plan to create model architectures for infants (weakly coupled across fields), young children (slightly stronger coupling), and adults (most robust coupling).

Word Count: 497

Parent Speech to Talkers and Non-Talkers: Changes in the Natural Statistics Across Development

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Objective

The objective of the present work is to describe how the natural statistics of parent speech change as children's verbal abilities develop. The authors achieve this objective by analyzing naturalistic speech recordings collected in the home – with no experimenters present.

Method

Using infant-perceptive head camera videos collected as part of the Homeview Corpus (http://www.indiana.edu/~cogdev/homeview.html#Homeview), parent speech in a natural context was analyzed for two groups of children: infants (10 children aged 7.0 to 9.8 months) and toddlers (9 children aged 18.4 to 24.3 months). The infant age range was chosen to be representative of the early stages of language learning before the onset of first words (Bergelson, & Swingley, 2012). The toddler age range was chosen to be representative of the vocabulary growth spurt during which children rapidly acquire object names (Ganger & Brent, 2004). Human coders transcribed all speech in the children's environments, and word frequencies were calculated for each age group (that is to say, using a corpus analysis approach). The children's own vocalizations were also transcribed to verify whether they had begun talking.

Results

Preliminary results show that parents' speech when in their children's' vicinity varies considerably depending on the developmental level of the children. Object names are more

frequent in toddlers' environments than in infants' though the total amount of speech does not differ between the two groups.

Conclusion/Discussion

The present results suggest that parents may attune their speech to their children's abilities. More importantly, the finding that the natural statistics of speech in children's environments differ across development has important implications for word learning. Parents' speech is the statistical input from which children must learn, and the present results suggest that their own abilities in some way shape the statistical input they receive. Thus, not only is the learner changing as he or she learns words, but the learning environment and the learning process are also changing.

Discrimination of Novel Objects in Infants and Adults

Key words: discrimination, perception

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Many research designs in developmental psychology use novel objects that researchers have created as a means to control infants' prior experience and the knowledge infants bring to the task (Horst & Hout, 2016). While we know that infants can discriminate stimuli differing in colour, shape and orientation, few studies have looked at how infants' abilities may be different from that of the adults who design novel stimuli. In part, this is because it is difficult to test infants in the long and extensive studies that are typically used with adults to establish the psychometric properties of stimuli (Huette and McMurray, 2010). Here we introduce a new task based on Ross-Sheehy (2003), that can be used with both adults and infants on the same stimuli and thereby enables comparison of discrimination with fine-graded stimulus changes. We also present data showing similarities and differences in the discrimination abilities of adults and infants in this task.

Short trials consisting of 1) a gaze-contingent attention grabber, 2) a memory array, 3) a retention interval, 4) a test array, and 5) a movie reward (Figure 1) were presented to Infants between 12- and 30-months and adults. Three sets of novel objects with well-controlled metric shape, colour and orientation properties were constructed. Shapes were defined by radial frequency components (Zahn& Roskies, 1972) that provide an evenly parameterized similarity space without category boundaries. Colours were sampled from a 360° continuous space (CIE*Lab 1976). Rotating each shape around its major axes of elongation generated orientations. Each set differed only on the examined dimension and were all the same on the other two dimensions. Within the examined dimension, adjacent stimuli differed by 15 degrees for a total of four discrimination steps. Eyes and legs are added to the objects to maintain infants' interest. There were 72 trials in 6 blocks that contained a test of each dimension and each step size. Ninety-four children and forty-three adults participated. Adults completed all 72 trials. Infants were run in as many trials as they would tolerate. The blocked design ensured that all infants contributed some data to all cells. Analysis compared looking to the change versus no-change side of the test array based on Areas of Interest (AOI) that surrounded each object.

Mixed models including random items revealed adults discriminated objects differing by 15 degrees in shape, colour and orientation and looked more with increasing step size for all three dimensions (Figure 2). However, adults demonstrated overall less looking to the shape changes compared to the other dimensions, suggesting that discriminations in shape were harder. Mixed models including random subject effects revealed infants discriminated changes in colour and orientation at step size 3 (45°) and 4 (60°) but did not discriminate changes in shape

(Figure 2). Analysis of developmental differences is ongoing. Our work suggests important differences in discrimination by adults and infants with well controlled stimuli. It also demonstrates a new task to probe infant discrimination across multiple dimensions and fine-grained stimulus changes, for comparison across development.

Figure 1

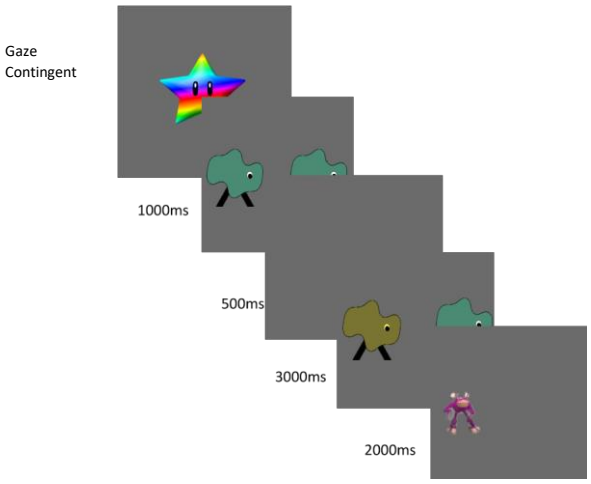
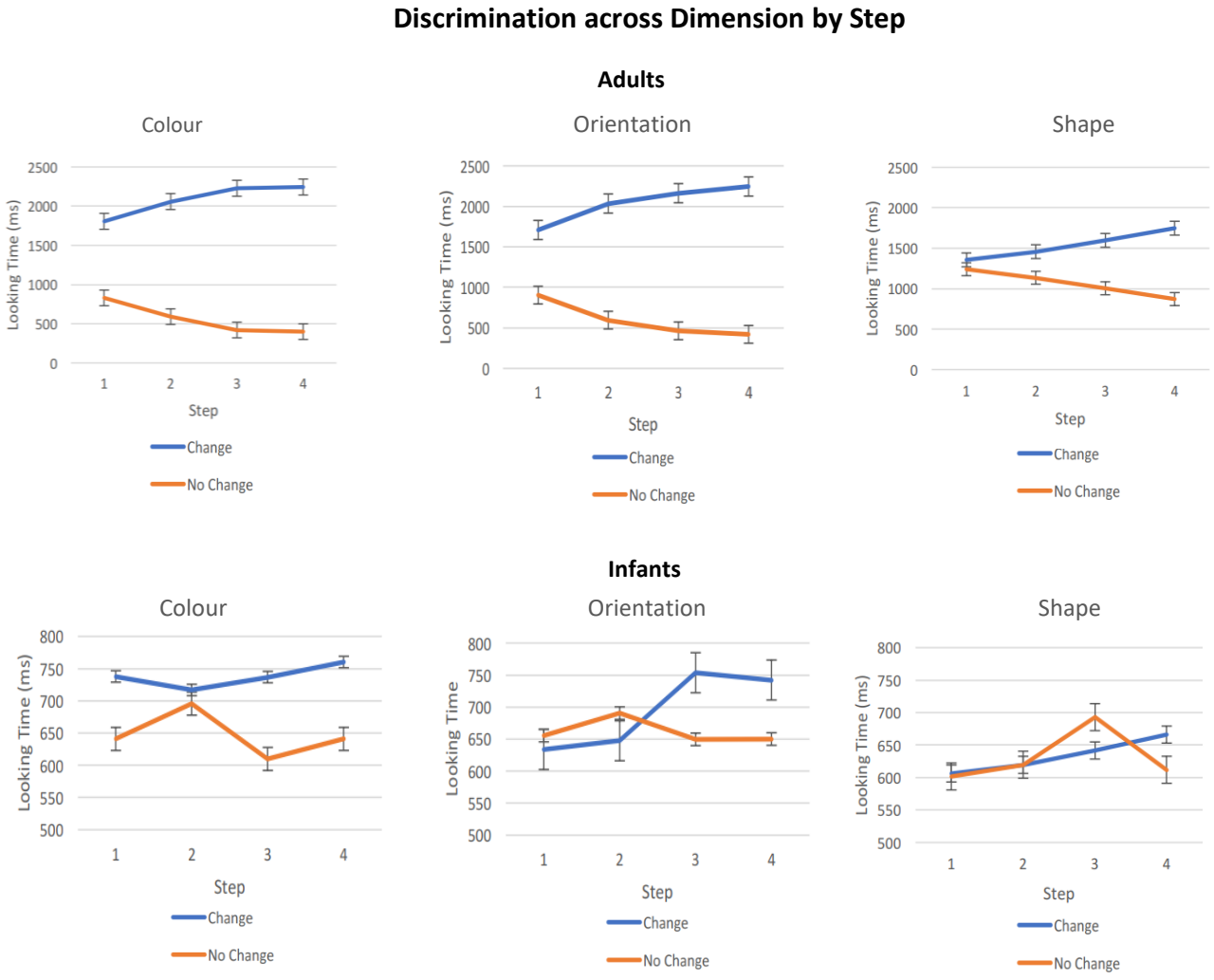


Figure 2



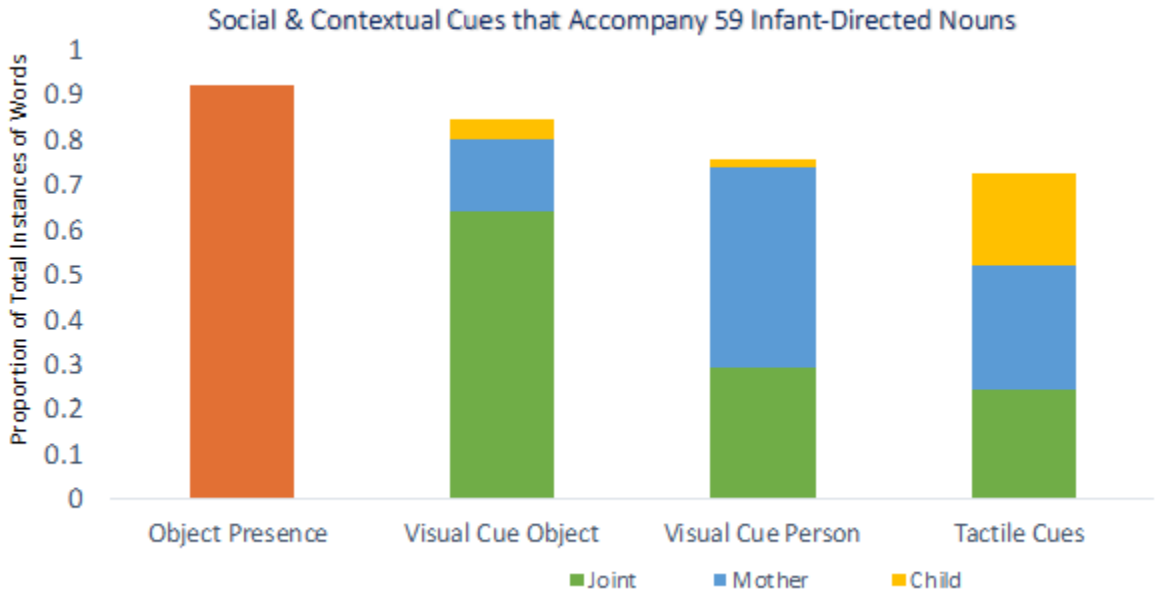
Dynamic cues and word learning: How everyday routines and locations in the home influence infant-directed speech

Stephanie Custode & Catherine S. Tamis-LeMonda

Infants' home environment is depicted as a "messy," "chaotic" place, where countless people, objects, and events all bid for infants' attention. In the lab, researchers control for distractors while studying early language development, offering little insight into how infants actually learn new words in their "messy" environments. What do children's natural contexts look like during word learning interactions? We investigated the dynamics of children's interactions, asking how language and day-to-day routines are distributed across daily activities and spatial locations in the home. Specifically, we asked: (1) Do caregivers' use of common nouns vary in predictable ways across their everyday routines and locations? (2) What visual and tactile cues accompany common nouns directed to infants in the home?

Participants were 40 healthy 13-month-olds and their English-speaking mothers in NYC. Dyads were video-recorded in home during their naturalistic routines for 45 minutes. Videos were transcribed, revealing, across the sample, 65,655 total words (with 1,811 unique words) directed to children. To detail the physical cues that accompany these words, we limited our scope to concrete nouns MacArthur Communicative Development Inventory (MCDI). Our final list included 59 target nouns spoken by at least 25% of mothers. We identified 3,219 naming events across participants and examined the 6-second of video around these events. Naming events were coded for object presence, mother and child's visual and tactile cues, routine type (mealtime, grooming, literacy, toy play, and unstructured), and spatial location (room, place within room; e.g. living room, kitchen, bathroom, and couch, highchair, changing table).

Analyses revealed that routine and spatial location systematically organized mothers' language. For example, mothers frequently used animal names (e.g., dog) when children engaged in literacy and toy-play, but almost never during other routines, such as mealtime. Likewise, food naming occurred while infants were in the kitchen (especially while seated at the table), and were infrequent in other spaces. Additional analyses revealed the interactions were rich with visual and tactile cues (see Figure 1). Mothers tended to use simultaneous visual and tactile cues to name objects that were physically present, while their infants used coordinating visual and tactile cues to reference and explore objects in the home. Together, these data reveal that the consistency of spatial locations and embodied cues during day-to-day interactions provide children with systematic, structural, and contextual cues to word meaning, scaffolding language development.


Social & Contextual Cues that Accompany 59 Infant-Directed Nouns
Proportion of Total Instances of Words
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Object Presence
Visual Cue Object
Visual Cue Person
Tactile Cues
Joint
Mother
Child

Attentional Precursors Of Executive Function In Early Development

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Executive Function (EF) refers to an interrelated set of neurocognitive systems that underlie behavioral control and cognitive flexibility. EF has pervasive influences on cognition and later development. Many studies have explored the development of EF from early childhood to adulthood (Carlson, Zelazo & Faja, 2013). A key challenge is to understand how EF develops early in development, before the age of 3, where early interventions might have the most impact.

Recent studies have investigated links between infant and toddler behavior and the emergence of EF (see Hendry et al., 2016 for a review). Early forms of attentional control, self-regulation, processing efficiency, and cognitive flexibility have been reported to show a predictive relationship with later EF (Hendry et al., 2016). Furthermore, evidence suggests that early emerging individual differences in attentional control and working memory may play a role in mediating later-developing differences in academic learning (Wass, et al., 2012).

The present project sought to explore potential early precursors of EF and how they change over development. Specifically, we investigated how *attentional control*, in the form of attentional orienting and executive attention, relates to EF. Participants aged 24-71 months (M=54.1, SD= 11.7; n=51) completed a Gap-Overlap task with an executive attention component modeled after Johnson et al. (1991). This task measures the ability to disengage from one stimulus to attend to another, the ability to show anticipatory looking, and the ability to use a cue to predict the spatial location of a subsequent target. Participants also completed the Minnesota Executive Function Scale (MEFS; Carlson & Zelazo, 2014). Finally, the Effortful Control temperament dimension was assessed using the very short forms of the Early Childhood Behavior Questionnaire (ECBQ; Putnam et al., 2010) and the Child Behavioral Questionnaire (CBQ; Putnam & Rothbart, 2006).

As expected, EF was highly correlated with age such that older children showed higher EF scores on the MEFS task, $r = .79$, $p<.001$. Interestingly, parent ratings of effortful control were not correlated with EF, consistent with previous research suggesting that parent-reported effortful control is primarily related to 'hot' EF tasks and not 'cold' EF tasks like MEFS (Carlson et al., 2004; Kochanska et al., 2000; Mulder et al., 2014). Further, data suggest that participants with higher EF scores on MEFS produced more correct anticipatory looks in the attention task. Thus, our results suggest that rudimentary forms of attentional control may play a key role in the development of EF.

Studying Developmental Trajectories in the Early Development of Speech and Tool Use with a Robotic Model

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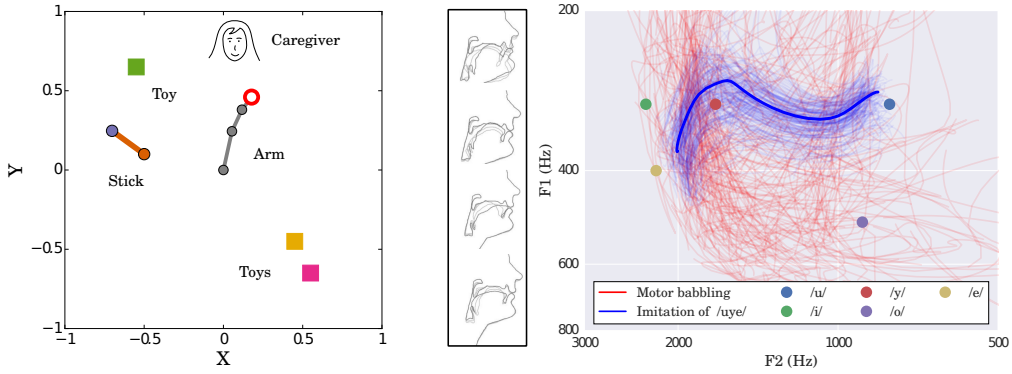
I. Introduction

Recent computational models of vocal development make use of a simulated vocal synthesizer that the learning agent must control in order to produce vocalizations, with the help of human sounds to be imitated [1], [2]. In [3], the agent chooses the strategy that shows the best competence progress: either autonomously training to reach phonetic goals, or trying to imitate human sounds. They show that the intrinsic motivation for learning progress self-organizes coherent infant-like developmental sequences. However, in those models, agents are not situated into a physical environment where vocalizations could have a meaning related to tool use situations. In a recent series of robotic models, we situated the learning agents in a physical environment with toys and tools and studied the learning of tool use from scratch, without any kind of pre-programmed reaching skills [4]–[6]. We have shown interesting similarities with infant development in terms of the developmental trajectories and strategy choice dynamics. In [7], we study the development of both speech and tool use in a unified simulated robotic model. Our model allows both learning from imitation of a caregiver and autonomous body babbling as in free play, and relies on two algorithmic ingredients: goal babbling and a modular object-based representation of task spaces. We hypothesized that learning to produce the name of toys in a natural play scenario is faster than learning other words because infants choose goals related to those toys and engage caregivers help by trying to vocalize those toys names. In line with this work, we started to model more precisely the interaction between the learner and the caregiver by giving the agent an attentional window during which it can link an event (such as the caregiver reacting to the agent) to its action. The agent imitates the vocalizations of the caregiver, and we now also allow the caregiver to imitate the vocalizations of the agent, which complexifies the interaction scenario. The objective is to understand in more details the emergence of developmental trajectories from the interaction between the learning agent and its capabilities, its environment, and the caregiver that reacts to the actions of the learner.

II. Methods



(a) Play Environment

(b) Examples of DIVA articulators, and sound trajectories

Fig. 1: Agent's robotic and vocal environment. (a) Agent's 3 DOF arm, controlled with 21 parameters, grabs toys with its hand, or uses the stick to reach toys. The caregiver brings a toy within reach if the agent says toy's name. (b) Agent's vocal environment representing sounds as trajectories in the two first formants space. The agent's simulated vocal tract produces sounds given 28 parameters. When the agent touches a toy, the caregiver says toy's name. Agent's sounds corresponding to random parameters are plotted in red, sounds produced when imitating caregiver's /uye/ are plotted in blue (best imitation in bold). The caregiver also imitates agent's vocalizations, if she recognizes the sound of the name of a toy.

III. Results

Preliminary results show that the grounded exploration of toys accelerates the learning of the production of accurate sounds for toy names, and that the interaction with a caregiver that imitates agent's vocalizations improves agent's vocal learning if the agent has an attentional window sufficiently large.

IV. Discussion

In our robotic model, agents learn different strategies to retrieve the toys: use the hand directly, use a stick, or vocalize the name of the toy to engage the caregiver to help. Some agents prefer one strategy more than another, or discover how to vocalize the name of the different toys in different orders. This individual variability and the trajectories of development emerge from the interaction between the learner, its attentional capabilities, its environment, and the contingent caregiver. We are currently studying in more details the mechanisms of and of it changes depending on the contingency of the caregiver, the attentional capabilities of the agent and the complexity of the environment.

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Dynamics of information sampling during the recognition of altered visual objects

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Objectives:
This study investigates subjects' exploration strategies for the recognition of visual objects, in relation to recognition difficulty and prior knowledge.

Methods:
Stimuli were generated using the "Dots" method (Moca et al., 2011), which allows for slowing-down the recognition process of visual objects in a controlled fashion. Using the contour information in an object source image, a deformation was applied to a 2D lattice of dots to displace dots and reveal the outline of objects. 50 different objects were used, with 7 gradual displacement levels. 12 participants were tested in a detection task where they freely explored each stimulus until they decided to press one of three buttons to indicate whether they had "seen" the object, were "uncertain", or saw "nothing". After the button-press, a message was displayed asking them to verbally name the object in the "seen" and "uncertain" (guess) trials. Stimuli were divided into 7 blocks of 50 trials, each containing all 50 objects for one displacement level. Stimulus order was randomised within blocks but blocks order was fixed, following one of two paths. 6 subjects were presented the stimuli in an "ascending" path, where the blocks had increasing levels of recognisability; the other 6 participants viewed the stimuli in a reversed "descending" order, starting with the easiest recognisability level. Subjects' button-presses and verbal responses were monitored and eye-tracking was used to record their eye-movements.

Results:
The method successfully slowed-down subjects' recognition process, who generated a relatively high number of fixations before they reached a decision. Using gradual changes in lattice displacement was also effective in modulating the difficulty of the task, as subjects' accuracy increased with displacement level. Additionally, the order in which the stimuli were viewed influenced subjects' responses and visual sampling behaviour. Descending participants were quicker at detecting objects accurately, and their fixations spread, count, and duration significantly differed from that of ascending subjects. To further characterise these differences, two correlated but distinct measures were used: the amount of information present in the image (local dots displacement from the lattice image) and the amount of information conveyed by the object itself (local contour density from the source image). Strikingly, subjects in the two groups sampled these two kinds of information differently: descending subjects fixated at points containing more of the hidden object information (contour density) and less of the salient image information (dots displacement). This suggests an effect of prior knowledge on subjects' performance and exploration behaviour.

Conclusion/Discussion:
The dots method is useful for studying recognition processes in a precise quantitative manner. Prior knowledge seems to guide observers' exploration behaviour and optimal sampling of information. Future work will try and characterise these effects during development.

Dynamics of interaction patterns in monolingual and bilingual infant-mother dyads

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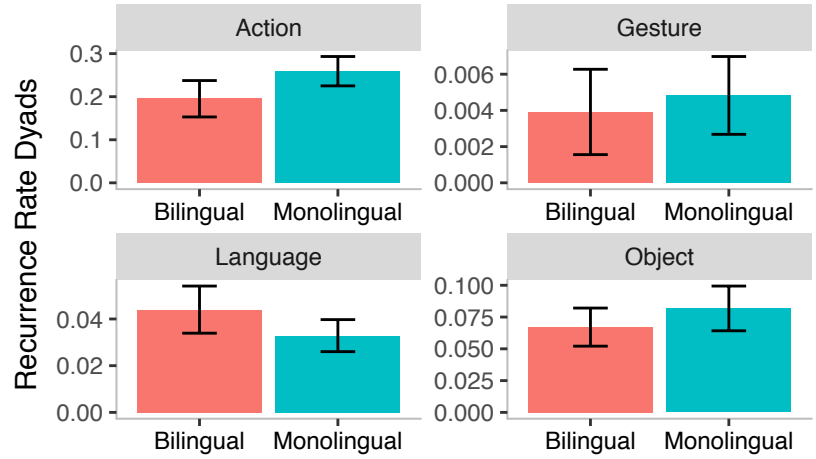
Research on bilingual children's development has pointed to advantages with respect to executive functions, learning languages, and reading communicative cues. The proposed mechanism for the reported advantages lies in the simultaneous activation of one language while simultaneously suppressing the other. However, it is yet unknown whether being exposed to two languages is enough to explain the advantages or whether cultural differences in the way of interacting similarly shape children's development. In this study, we took a first step to disentangle the relative contributions of language and interpersonal interaction styles. We investigated the verbal and non-verbal interaction patterns of monolingual and bilingual infants with their parents at the ages of 12-15 months.

We tested 40 monolingual (mean age = 409 days, SE age = 9 days) and 40 simultaneous bilingual children (mean age = 414 days, SE age = 7 days). Using the decorated-room paradigm with additional toys to play with we observed the infants with their accompanying mothers during 5 minutes of free play. We micro-coded all acts in the categories *language*, *action*, *gesture,* and *objects* for mother and infant and subsequently used cross recurrence analyses to determine the characteristics of the interpersonal interaction patterns. Here, we present preliminary data of the first quarter of dyads.

We analysed the differences between monolinguals and bilinguals in the following two dependent variables: 1) Recurrence rate informs about the amount of shared interaction states; 2) Trapping time informs about the duration in which infant and mother stayed in a shared behaviour for all categories (language, gesture, action and objects). We found a significant model fit with our data for the recurrence rate (estimate = 0.19, $SE = 0.02$, $t = 9.15$, $p < .001$). Language group was a significant predictor of recurrence rate with a positive estimate for monolinguals (estimate = 0.06, $SE = 0.03$, $p = .003$) and no interaction effects. For trapping time, the model also fitted our data (estimate = 492.89, $SE = 42.24$, $t = 11.67$, $p < .001$). Language group was again a significant predictor for trapping time with a negative estimate for monolinguals (estimate = -284.71, $SE = 58.32$, $p < .001$). This group difference was not strongly pronounced in language (estimate = 281.01, $SE = 72.93$, $p < .001$) and was reversed for gesture (estimate = 313.76, $SE = 79.59$, $p < .001$).

These results show that already at the end of the first year, monolingual and bilingual infant-mother dyads differ in how they interact with each other and how long their synchronous behaviour lasts. Monolingual dyads were more often in a synchronous state, bilingual dyads shared a synchronous state a longer time in actions and objects. This suggests that bilinguals' development is characterized by differences in interaction patterns. In addition to the exposure of two different language structures, differences in interaction patterns might have an additional effect on bilingual's development.

A



B

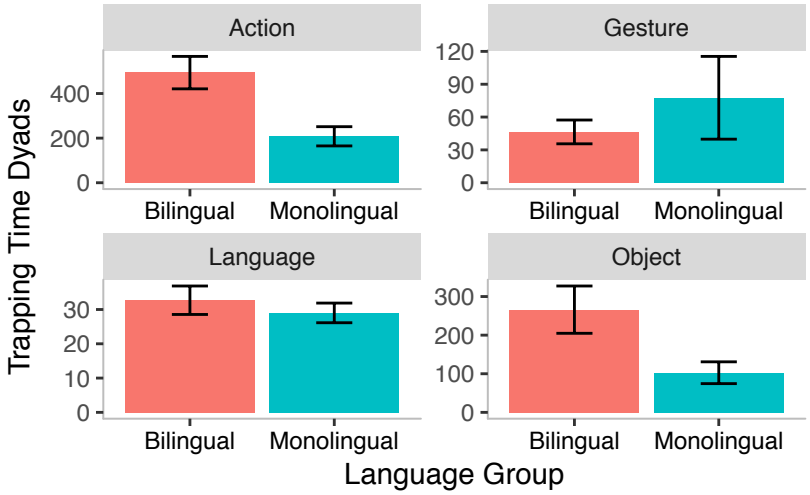


Figure 1: Mean and standard error of the two cross recurrence measures recurrence rate (A) and trapping time (B).

Title: Memory interference in monolingual and bilingual 18-month-olds
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Objectives: Introduction of novel information can result in retroactive interference as early as 3 months of age and persists across the lifespan (Rossi-George & Rovee-Collier, 1999). The present study examined whether there are differences in retroactive interference between monolinguals and bilinguals at 18 months using a deferred imitation paradigm. Bilingual children show consistent advantages when there are conflicting demands on attention: they are better able to selectively attend to the relevant cue in order to process the current goal compared to monolingual children (e.g., Rhee-Martin & Bialystok, 2008). Given that bilinguals have an earlier emerging ability to respond to response conflict than monolinguals, we predicted that bilinguals will be less likely to experience retroactive memory interference.

Methods: 23 participants have participated (15 monolingual, 8 bilingual) in the interference condition. Data collection is ongoing. There are three sets of test stimuli (puppets: cow, duck, tiger; rattles: A, B, C; and animals: rabbit, monkey, panda). There are three target actions for each set of stimuli. Infants saw target actions demonstrated on two different stimulus sets (set A and B). Then the experimenter tested infants with stimulus A. For example, a participant saw the duck puppet demonstrated 2x, the tiger puppet demonstrated 2x, and then was tested immediately with the duck puppet. Based on pre-established parameters, the puppet test phase lasted 90 s and the rattle and animal test phases both lasted 60 s each. The order of imitation tasks was counterbalanced. Imitation scores were calculated for each task (max = 3 target actions per task) and a composite score (max = 9) was created. Performance was compared to pooled baseline estimates collected via multiple prior studies using the same imitation tasks.

Results. The results were not in line with our prediction. Due to our small sample size, our preliminary data analysis involved a series of t-tests. When comparing the composite score, there was no significant difference between monolinguals and bilinguals, $t(17) = 1.14$, *n.s*. However, when comparing monolinguals to bilinguals on the puppet task, bilinguals performed significantly worse, $t(17.5) = 2.34$, $p=.04$. Note df is due to unequal variances. There were no differences on the rattle or animal tasks, both t's <1. Performance by each group was also compared to pooled baseline controls (puppet = .17, animal = .30, rattle = .60). Every group on each test performed above baseline except for the bilinguals tested with the puppet.

Discussion. The findings suggest that bilingual infants were more susceptible to interference on the puppet task when the perceptual features of the test objects were very similar. There was no difference in performance on the animal and rattle tasks where the perceptual features were more distinctive. Bilingual infants may be highly sensitive to visual perceptual cues early in development.

Table 1. Mean and SD of monolingual and bilingual infants on each test and composite score

Imitation score	Monolingual	Bilingual
Puppet test	0.93 (1.28)	0.13 (.35)*
Animal test	1.25 (.97)	1.00 (1.07)
Rattle test	2.33 (.78)	2.38 (.91)
Composite Score	4.67 (1.97)	3.57 (2.07)

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Infants' Anticipation of Others' Action in Edited Film Sequences

Adults (Flanagan & Johnson, 2003), as well as 12-month-old babies (Falck-Ytter, Gredebaek & Hofsten, 2006) perform goal-directed, anticipatory eye movements when observing real and filmed actions performed by others. The study we will present aims to find out what happens when the observed action is presented in an edited film sequence. For anticipating future actions segmenting event into units is critical. Infants could use these initial groupings to discover more abstract cues to event structure, such as the actor's intentions, which are known to play a role in adults' global event segmentation (e.g., Wilder, 1978; Zacks, 2004; Zacks & Tversky, 2001).Visual sequence learning is a primary mechanism for event segmentation and research show that eight-month-old infants are sensitive to the sequential statistics of actions performed by a human agent (Roseberry et al., 2011). Adults (Baldwin, Andersson, Saffran, & Meyer, 2008) as well as infants in their 1st year of life (Stahl, Romberg, Roseberry, Golinkoff & Hirsh-Pasek, 2014) can segment a continuous action sequence based on sequential predictability alone, which suggest that before infants have top-down knowledge of intentions, they may begin to segment events based on sequential predictability.

The stimuli used in the above mentioned infant studies present actions recorded from one camera angle in a single run (no cut). However in the commercial films –even the ones produced for very little ones- we see actions recorded from different angles and edited together later on. Regarding the fact that today many infants begin consistently watching television at 4 months of age (Christakis, 2011), become regular viewers when they are two years old and those exposed to television spend between 1 to 2 hours per day doing so (Zimmerman, Christakis & Meltzoff, 2007), it is important to understand how infants perceive televised actions and events as they are presented in popular media.

For the present study, we produced two sets of film clips depicting two conditions. In the first set of films an adult sitting in front of a table moved the objects placed to the one side of the table to the other side. In the second set of films, a child clapped her hands and stomped her feet in turn. In the Single Shot Condition, actions were shown in one long single shot. In the Multiple Shot Condition the actions were segmented into sub actions through multiple close-up shots. All film clips end with a long single shot paused after three repetitions of the actions (test shot) to measure anticipatory saccades. Infants (N=20) and adult controls (N=20) watched videos. Participant eye movements were recorded using a Tobii TX300. Analysis of gaze behaviour during this test shot showed clear anticipation in the adult control group in both conditions. Data collection for the infant sample is on-going but preliminary results indicate that 12 month-old's can successfully anticipate the actions in the unedited version but are less successful across edits

Figure 1: Sample pictures of stimulus videos. (a) Edited (b) Unedited. Both versions end with a long single test shot.

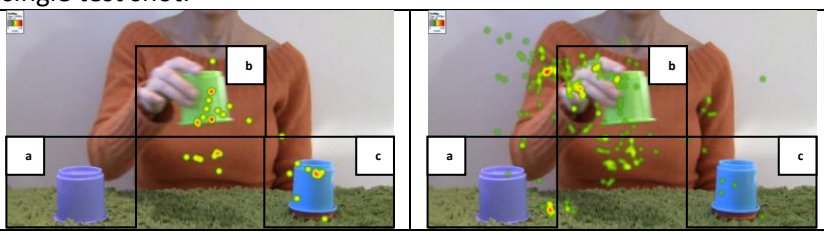

Figure 2: Heatmaps with Area of Interests for one of the edited videos. (a) Object AOI. (b) Trajectory AOI (**c**) **Goal AOI.** Right: Babies, Left: Adults

Infants generate structured learning environments during curiosity-driven category exploration

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Decades of developmental research offer a rich picture of the factors implicated in the fundamental skill of early category learning. However, with a few exceptions, these studies typically control stimulus order and timing *a priori*. Outside the lab, in contrast, infants explore their learning environment freely. Surprisingly, given the ubiquity of this curiosity-driven learning in early development, it is yet to be fully characterised. However, recent computational work (Twomey & Westermann, 2017) predicts that systematicity in curiosity-driven exploration should unfold dynamically as infants move from stimulus to stimulus, generating an intermediate level of task complexity. The current study tests this prediction in a free exploration task.

To quantify complexity we developed three categories of 3D printed toy objects, each consisting of five exemplars varying along a continuum. For example, the *pyramids* category consisted of a triangular pyramid, then a four-sided pyramid, then a five-sided pyramid, and so on. Twelve-, 18- and 24-month-old children ($N = 54$) then took part in a shape priming task (Twomey, Malem & Westermann, 2016). Children saw six trials (two per category), during which they played with a prime object from one end of the continuum for 15 seconds, then the remaining four objects 30 seconds.

To test the hypothesis that infants explore systematically, we coded for first touches and transitions between objects. Transitions between objects were a proxy for perceptual distance; for example, a transition from the second object in a category to the third constituted a distance of 1, and a transition from the second object to the fifth was a distance of 3.

First touches were non-random (12mo: $\chi^2(3) = 12.09$, $p = .001$; 18mo: $\chi^2(3) = 22.84$, $p < .001$; 24mo: $\chi^2(3) = 8.05$, $p = .045$); specifically, infants initially systematically chose the most distant object, irrespective of prime. Next, we submitted exploratory sequences to a hierarchical cluster analysis to determine whether infants' dynamic exploration was also structured. These analyses detected clusters in all age groups' exploratory sequences (12mos: 3; 18mos: 3; 24mos: 2). To characterize these clusters, we coded each sequence by prime, mean transition distance, sequence length, and entropy. We then used these indices to predict cluster membership in a series of multinomial regressions. Across ages, mean distance cluster membership (all ps $< .0051$); specifically, infants systematically generated sequences of intermediate distances. Cluster membership was also predicted by sequence length (all ps $< .00023$).

In line with Twomey & Westermann (2017), infants generated systematic exploratory sequences when engaged in curiosity-driven object exploration. Specifically, the unfolding of these exploratory sequences in time indicates that infants prefer intermediate complexity (cf., Kidd, PIantadosi & Aslin, 2012). Overall, this work demonstrates that infants are neither passive learners nor random explorers; rather, they structure their own learning environment. Thus, we highlight the importance of taking seriously this dynamic learner-environment interaction for a clear understanding of development.

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Title: Using a Dynamic Neural Field Model to Explore the Effects of Action on Memory

Objectives: A fundamental idea proposed by Dynamic Field Theory is that cognitive processes interface with perception-action systems in real-time. One such example of this interaction suggests that participants have worse memory recall of stimuli from a go/no-go task which elicit inhibition (no-go) of a motor response than stimuli which afford the execution (go) of a motor response (Chiu & Egner, 2016). This effect has been explained through competition for common neural resources: allocation of resources toward response inhibition reduces the amount of resources available for memory. Alternatively, this effect could be driven at the level of perception-action coupling: engaging and pairing the motor system with visual perception enhances the memory of stimuli which elicited the motor preparation or response. Testing this alternative account, we developed a dynamic neural field model that implements systems of memory and perception-action coupling. In this way, we explore how activation in memory formation is influenced by the execution of motor responses.

Methods: We utilized a three-layer working memory (WM) system: stimuli are encoded into an active representation state in a WM field that is coupled to a response-selection (RS) system. The RS system implements pre-shapes to engage responses for stimuli based on stimulus-response associations. Additionally, an attentional unit was implemented to take part in different task states: when the attentional unit is engaged, it allows activation to pass between the WM and RS systems, but when the attentional unit is inactivated, the WM and RS systems do not interact. The model received a series of go/no-go trials in which the attentional unit facilitated interaction between WM and RS systems and a series of trials absent of motor engagement (neutral) in which the attentional unit returned no such outcome. Lastly, we included a memory trace field which is coupled to the WM field. This field accumulates a memory trace that is a function of activation in the WM field and is used as a proxy for recognition memory for particular stimuli. After administering the series of go, no-go, and neutral trials, we then examined the strength of memory traces accumulated for these trial types.

Results: Superior memory trace activity was observed for go stimuli; building a response peak in the stimulus-response system boosted the WM representation of the stimulus. Memory traces were next strongest for no-go stimuli; below-threshold interactions between the RS and WM system led to facilitated memory trace accumulation. The weakest memory traces were returned on neutral trials; with no external catalyst to enhance interaction between the RS and WM fields, memory trace peaks for these stimuli were reduced.

Discussion: These simulated dynamics demonstrate a real-time link between systems of perception-action and cognition; as motor preparatory and response processes are engaged to go/no-go stimuli, perceptual processes scale memory trace peaks relative to neutral stimuli. We are currently utilizing fNIRS to uncover the neural networks implicated by these simulations.

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Title:

Simulating interactions between evolution and development in the selection of domain-relevant learning properties, under a polygenic model of cognitive variation

Abstract:

Researchers in cognitive development have long debated whether the infant arrives in the world fitted with domain-general learning abilities, or learning abilities specific to particular cognitive domains – illustrated by the famous debates between Piaget and Chomsky on language acquisition (Piattelli-Palmarini, 1980). An intermediate position proposes that learning abilities are 'domain-relevant' (Karmiloff-Smith, 1998). That is, developmental mechanisms have learning properties that are better or worse suited to acquiring certain domains. This would explain, for example, why structural elements of language are usually acquired in the left hemisphere of the brain, even though the right hemisphere can adequately acquire these elements following early damage to the left hemisphere (Bates & Roe, 2001). The left hemisphere has processing properties more closely suited to processing language structure than the right – so usually wins out in a competition – but the right hemisphere has properties and connectivity that allow less optimised acquisition of the same skills.

Evolution and development are part of a single dynamical system. For domain-relevant learning properties to be present at birth, they would need to be selected for by an evolutionary process ultimately acting on the species' genome. However, the traits that evolution selects (via differential reproduction) are the product of the developmental process.

With respect to human behaviour, and particularly high-level cognition, the current consensus is that variation in cognitive ability is result of many small genetic contributions, influencing many properties of brain development and function, the so-called polygenic model (Plomin et al., 2016). This raises the question of how evolution could simultaneously select or 'tune' multiple processing properties of neural systems to imbue domain-relevance.

In the current work, we used computational modelling to investigate how domain-relevant learning properties could evolve in such polygenic systems. Populations of

artificial neural networks (ANN) were exposed to differently structured learning environments. Following principles of behaviour genetics, variation was introduced in to the population of learners both in terms of their learning ability and the richness of the environment to which each individual was exposed (Kohli, 2017; Thomas, Forrester & Ronald, 2016). The behaviours the networks acquired were used to select the fittest individuals in each population. The learning ability of each network was specified by ANN parameters such as the learning rate, momentum, and architecture. These were encoded in an artificial genome. The fittest genomes were used to produce the next generation by a simulated process of sexual reproduction.

We refer to a sequence of populations produced under selection as a *lineage*. Five different associative learning environments were created which we anticipated would pose different computational challenges for a learning system (autoassociation, categorisation, categorisation with exceptions, quasi-regular mappings, arbitrary association) and so encourage the selection of processing properties optimised for each environment. A lineage was created for each problem, with 1000 networks per generation and 20 generations. As expected, population performance increased down lineages. Notably, as we followed the emergence of the five lineages, we could also assess how adequately a given population of genotypes in a lineage could acquire the behaviours of any of the other four environments for which it had not been selected, that is, where processing properties were increasingly *domain-irrelevant*. We could therefore trace the divergence of domain-relevance and domain-irrelevant processing properties in the development of behaviour.

In order to analyse the emergence of domain-relevance, we tracked the mean value of each computational parameter across generations in each lineage. We observed that selection occurred on combinations of parameter values, rather than individually, in line with the polygenic model. We integrated a twin-study design into our simulations that permitted measures of the *heritability* of acquired behaviour (Kohli, Magoulas & Thomas, 2013) – that is, the proportion of phenotypic variability explained by genetic variation. Heritability dropped for behaviours that had been selected, in line with reduced genetic diversity. Only the best genes were retained across generations. However, heritability stayed level or rose when these populations acquired domain-irrelevant skills. High heritability equated to a lack of selection. Lastly, we observed an evolutionary parallel to Waddington's developmental epigenetic landscape (Waddington, 1957): when a particular combination of parameters had been selected as relevant – and genes for other parameters discarded – the fate of lineage became restricted to particular (sometimes sub-optimal) computational solutions for acquiring a domain. This was a consequence of the polygenic relationship between the heritable substrate of domain-relevance and the behaviours that development produces.

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Dynamics in the early lexicon: Individual differences in word learning

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Objectives

Over the second and third year of life, a child's vocabulary grows drastically, from a handful of words to an average of 553 words by the age of 30 months (1). Although the general pattern is stable across children and languages, there are considerable individual differences in the words known to different children: German vocabulary data (2) suggests that, at 20 months, 52% of children produce the word *Bagger* 'digger' and 48% of children produce the word *Bär* 'bear'. Importantly, of the children who produce at least one of these words, 52% of them produce the one but not the other. What determines whether a child is a *Bär* baby or a *Bagger* baby? Recent approaches to word learning highlight different timescales as well as the child's interests and experiences.

Samuelson and Faubel's (4) unified theory brings together recent accounts of word learning in a dynamic framework. Special emphasis is placed on memory traces that accumulate over time and depend on what the child hears. If children solicit information based on their interests (5, 6), memory traces should accumulate faster for categories that the child is curious about. Thus, thanks to the introduction of memory traces, a dynamic framework might help us better understand how curiosity and knowledge interact in word learning.

Methods

In an ongoing study, we investigate the influence of category curiosity and category density on the acquisition of new word-object-associations. 30-months-olds (n=22) were, first, presented with 16 familiar objects from two broad (M = 31 members) and two narrow (M = 11 members) categories and heard their corresponding labels while their pupil dilation response was measured as an index of their interest in members of the different categories. Next, they were exposed to novel members from each of the four categories and tested on their learning of the new word-object-associations. In addition, a vocabulary questionnaire and a questionnaire on the child's interests in different category members were administered.

Results

Analyses indicate that children are able to learn novel members from both broad and narrow categories, but learning is more robust in the broad categories. This suggests that children are able to leverage their existing semantic knowledge to learn new words, which is in line with previous research (e.g., 7, 8). Additional pupil dilation analysis has shown that learning is impacted by children's inherent curiosity in objects from particular categories: Learning outcomes for novel members of a category are positively correlated with pupil dilation as measured on familiar members of the same category.

Conclusion

Our findings suggest that the child herself is a major source of variability in early word learning. What a child is interested in will shape what she learns next, leading to individual differences that are observable early on. This is consistent with a developmental dynamics framework in which memory traces, based on past experiences, play a major role in early word learning: Whether a child is a *Bär* baby or a *Bagger* baby depends on which memory traces she accumulated over time.

499 words

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Title: Preferences for human motion configuration in the first half of the first year of life

Isabel C. Lisboa, Daniel Basso, Sandra Queirós, Jorge A. Santos & Alfredo F. Pereira

Objectives

There is an early and distinctive sensitivity to biological motion (BM), the motion of animate beings. Infants as young as 2 days old, in a preferential looking paradigm with the point-light technique, prefer to look at a canonical point-light-display (PLD) over random motion or inverted motion (Simion, Regolin & Bulf, 2008); however, when a spatially scrambled control is used, newborn's preferences are absent (Bardi, Regolin & Simion, 2011). Spatially scrambled displays correspond to randomizing the initial position of each point in a point-light-display, thus, the individual dot's local motion is maintained but the coherent human motion configuration is disrupted, in particular there is no articulated motion (i.e. rotations about a joint).

The aim of the present experiment is to ascertain *if* and *when* a preference for either stimuli (canonical point-light-walker – PLW – vs. scrambled PLW) arises in infancy.

Methods

Two groups of infants were tested in a preferential looking procedure: N = 25 infants with 3 months-old (mean age = 3 months and 12 days) and N = 20 infants with 5 months-old (mean age = 5 months and 14 days).

Infants were tested with two motion stimuli: (1) a canonical PLW and (2) a spatially scrambled version of this display (scrambled PLW). Both PLWs described a frontal approaching motion with no translation and infants participated in 6 trials of 60s each. To be included in final sample, participants had to have sufficient looking time and not show any side bias. Final sample consisted of n = 15 three months-old infants and n = 12 five months-old.

Results

To assess the differences between the mean looking time at both stimuli, we conducted a one-way ANOVA with the mean difference as the dependent variable

and age-group as factor. Differences between means of the two groups were statistically significant, $F(1, 25) = 5.44$, $p = 0.028$). All 3-months old infants (except one infant) spend more time looking at the canonical PLW; this pattern was not present at 5 months of age – see figure 1.

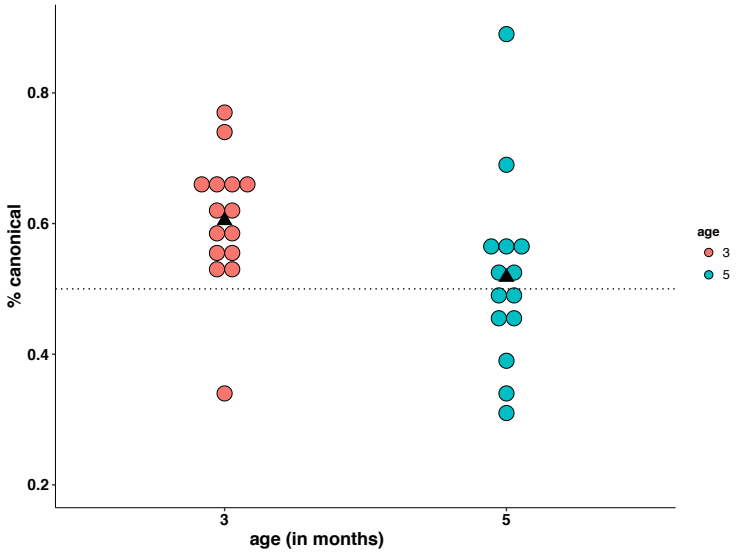

Figure 1: proportion of looking time to the canonical PLW at 3 and 5 months old. Each dot represents each subject proportions; the triangle corresponds to the mean proportion per age.

Conclusion/Discussion:

We did not observe an increased preference, across developmental age, towards a canonical PLW. In contrast, analysis of individual infant's fixation patterns, across trials, revealed that 3-month olds fixate the canonical PLW in sustained longer periods – this pattern was consistent across the entire sample. The fixation patterns for 5 month olds is markedly different, with shorter fixation bouts and fast switching between canonical and scrambled.

We hypothesize that at 5 months of age, both stimuli are perceived as simply two competing motion displays, without any inherent categorization (e.g. as human vs. non-human) (Bertenthal, Proffitt & Cutting, 1984). The two stimuli also differ in terms of complexity, with the canonical PLW having higher configural coherence (Bertenthal, Proffitt, Kramer, & Spetner, 1987) – and differences in complexity seem to affect infant's preferences patterns (Kidd, Piantadosi & Aslin, 2012).

Classroom dynamics and language development: How peer social interactions affect preschoolers' language outcomes

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A rich body of literature has examined the relation between the linguistic input children receive and their subsequent language development. Such studies have revealed that the quantity of speech, grammatical complexity, and variability of the vocabulary used in caregivers' speech were associated with children's language gains. However, little is known about the role peers and preschool classroom interactions play in this process. This is in part because our current understanding of early classroom social interaction relies primarily on teachers' observations and experts' manual coding of interactions, which provide insightful snapshots of classroom dynamics but are limited in the scope of information acquired simultaneously. Here, we employed objective, continuous measurements of children's location and vocalizations in an early intervention classroom to examine the influence of peer interactions on children's language use.

Data were collected weekly over ten consecutive weeks in an inclusive intervention preschool classroom of seven Deaf/Hard-of-Hearing children with cochlear implants and three typically hearing peers (M_{age}=36.8 months, SD=3.3 months). Continuous, objective measurements of children's location and orientation were collected using the Ubisense system. The classroom was outfitted with four sensors that tracked active tags worn by children using radio-frequency identification. Periods of social contact were defined as instances where children were within 1.5m of each other, a distance at which co-location between children occurs more than would be expected by chance, and were also oriented toward one another within 45°. Children also wore Language ENvironment Analysis (LENA) audio recorders, allowing for automated analysis of day-long vocal recordings. Synchronized LENA and Ubisense measurements indicated when children were in social contact and vocalizing.

Linear mixed-effects models were employed to predict children's language use from the proximal input of their peers. Each child had variable levels of social contact with their peers in the course of an observation and during those periods of social contact their peers vocalized at different rates. Children's total vocalization levels during each observation were positively predicted by their peers' input during social contacts in the previous week, b=0.90, se=0.31, t=2.89, $X^2(1)$=8.30, p<0.01 (**Figure 1A**). Specifically, children who received the most input in a given week generally vocalized more, regardless of their social partner, during the subsequent week. Additionally, the amount of input children received from each of their social partners positively predicted the amount of vocalizations they produced when interacting with those same peers the following week, b=0.36, se=0.11, t=3.30, $X^2(1)$=10.77, p<0.01 (**Figure 1B**). Interestingly, the relationship between peer input and children's subsequent language use was

not driven by a general increase in language use over time, as there was no effect of time in study on children's vocalizations. Furthermore, there were no main effects of hearing status on language use—suggesting that peer interaction is crucial for this at-risk population.

By capitalizing on automated, objective measurement techniques, this investigation allowed us to examine, in heretofore inaccessible ways, the mechanisms by which peer language input promotes children's language development. These findings highlight the crucial role of peer interactions in children's language production and development.

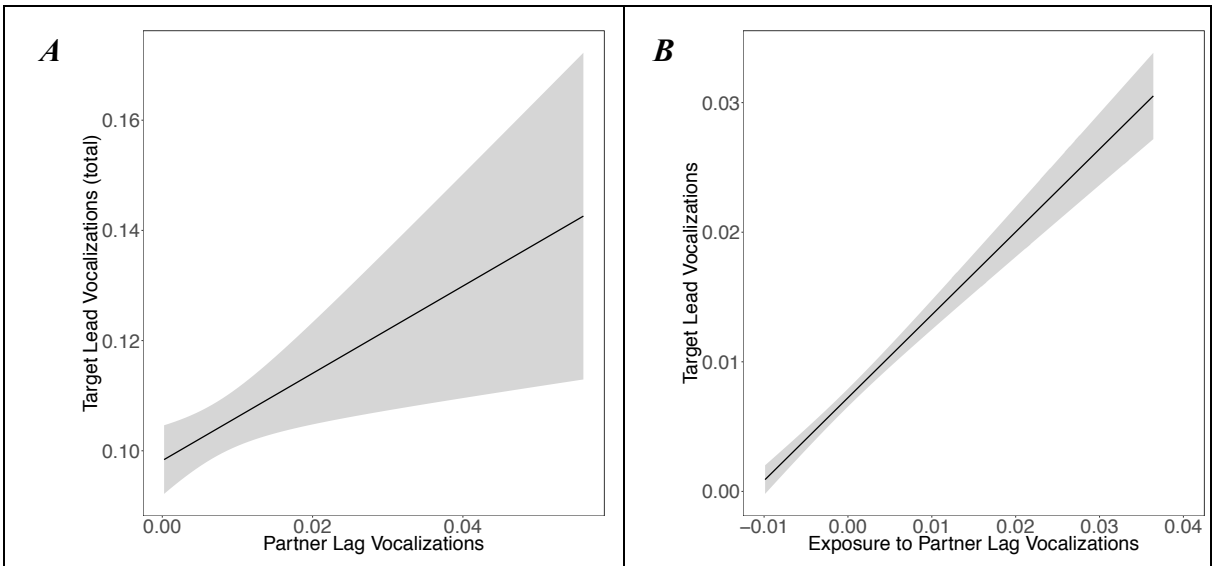

Figure 2. Slopes from multilevel models of classroom observations. Children's social exposure to their peers' vocalizations predicts **A)** their overall vocalizations regardless of their social partners and **B)** their vocalizations with the specific social partners from which they receive input.

Title: Exploring the Neural Mechanisms of Communication and Cooperation in Children and Adults

Sara Mosteller[1], Larissa K. Samuelson[1], Sobanawartiny Wijeakumar[2], John P. Spencer[1]

Objectives: How are humans able to communicate semantically and cooperate to jointly achieve sophisticated goals? How do these abilities develop from foundational building blocks in early childhood? The central aim of this study is to probe both the neural and behavioral mechanisms of learning and cooperation in a naturalistic, interactive and developmental context. We have adapted a paradigm for novel noun learning developed by Samuelson, Smith, Perry and Spencer (2011) to a hyperscanning paradigm (Cui, Bryant & Reiss, 2012) This project measures coordinated brain activity between a parent and child using simultaneous functional Near Infrared Spectroscopy fNIRS in pairs of 2.5, 3.5 and 4.5 year old children and their parents. We are also separately testing pairs of adult friends. The first hypothesis is that visual joint attention during the session will be positively correlated with both the number of words learned and with the number of blocks moved during a cooperative game of Jenga, between the parent and child or between the adults. The next hypothesis is that successful communication of new words and success in the Jenga game will each be positively correlated with synchronized brain activity between the parent and child/the adult friends in cortical regions underlying social cognition, semantic processing and visual working memory. *Method:* Children and parents, or adult friends, are seated across from one another at a table. The parent (in the developmental study) then teaches their child the names of novel toys. An experimenter then tests the child by presenting the objects in pairs and asking the child to retrieve one object by name. Children are asked to choose from both pairs of familiar objects and pairs of novel objects. In order to explore individual differences in cooperation with the same participants, each dyad plays a cooperative game of Jenga, in which their joint score is based on how many blocks they can remove from the tower as a team. *Results:* A preliminary analysis of the noun-learning task showed that, when presented with 6 word-object mappings, children learned an average of 3 new words (50%) and that the number of objects learned by each child ranged from 2-4. Adults initially learned all of the new words but were variable in their later retention of the mappings, which ranged from 50-100%. We are currently examining differences in cooperative behavior during the Jenga playing game, including time spent discussing each move before it is made. Ongoing analyses are examining the social dynamics that might underlie the differences between words that were successfully learned and unlearned words for each dyad, as well as the developmental differences observed in the study. Additionally, the Jenga game is being used to better understand individual and developmental differences in social coordination during a cooperative task. At a behavioral level, the analysis maps periods of joint visual attention between participants during the word learning and the Jenga game, using head mounted eye trackers to assess each participant's first-person viewpoint during the session. We are also analyzing the coherence in brain activity between participants during novel word-learning and Jenga playing. *Discussion:* To the best of our knowledge, this study is the first to probe both the neural and behavioral mechanisms underlying cooperation and word learning in a developmental context, using a hyperscanning paradigm.

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Abstract

Attention Control in Task-Switching and Modality-Shifting Across Development

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Preschool years are marked with a rapid development in cognitive control of shifting attention. Being able to shift attention rapidly between different tasks at will potentially underlay cognitive flexibility. Switching tasks in real life often involves cross-modal attention shift. Atypical patterns of task-switching and cross-modal attention shift were found in children with attention disorders such as ADHD (Cepeda, Cepeda & Kramer, 2000) and ASD (Reed & McCarthy, 2011). However, little is known about how attention control, in task-switching and modality-shifting, are related, and how they change through development.

It is generally believed that switching to another task taps into cognitive control. If so, processing costs associated with task-switching may be mediated by age. On cross-modal attention, it is less clear if cost in shifting attention crossmodally is comparable to switching attention between tasks, and whether it also taps into developmentally sensitive cognitive control. To understand how children and adults process task-related information in a multisensory environment, we carried out two behavioural experiments and computationally simulated the results with interactive activation networks.

Four-year-olds (N=54), six-year-olds (N=51) and adults (N=50) participated in two novel cross-modal task-switching studies with either bimodal stimuli or unimodal stimuli. In the experiments, the participants were asked to press a key whenever they detected the target category using a one-button response key, and the detection target changed intermittently according to the task cue. Targets appeared randomly in either modality. Response latency costs in task transition (task-switch vs. task-repetition), and modality transition (modality repetition vs. modality-repetition) were analysed.

Shifting attention between tasks and between modalities produced significant performance costs in both experiments, in particular reliable RT costs (bimodal stimuli: $p<.005$ [Task Transition], $p<.001$ [Modality Transition]; unimodal stimuli: $p<.001$ [Task Transition], $p<.050$ [Modality Transition]). Although young children were less accurate and slower than adults overall ($ps<.050$), young children did not exhibit larger task-switching or modality-shifting costs in RT than adults (Task Transition X Age, $ps>.080$; Modality Transition X Age, $ps>.400$, across both experiments). In all, children as young as 4 years of age appear to be equipped with the requisite skills in flexible attentional control, incurring no larger costs associated with attentional shift than adults. To understand how children can be overall poorer in performance yet do not exhibit larger trial-by-trial costs, we simulated the results with computational modelling. Specifically, we looked at how parameters such as the strength of inhibition between task-associated elements, connection weights across the processing stages (i.e. processing speed), and the level of stimulus-task priming effect can result in global and trial-by-trial performance changes.

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Title

Mutlimodal turn-taking: First approaches

Objectives

In this paper, we notice that turn-taking as a fundamental mechanism of social exange is a multimodal phenomenon that has been – so far – investigated mostly as unimodal. According to theoretical positions emphasizing that communication is organized by the interaction partners jointly, we identify the challenge of assessing human sequential behavior that is (i) spread across different modalities and (ii) co-constructed with a partner.

Methods

Analyzing a corpus of mother-child dyads applying Cross Recurrence Quantification Analysis and frequent pattern mining, we offer first steps towards the problem of multimodal turn-taking.

Results

With these analyses, CRQA and frequent pattern mining, provide some support and initial results for the proposition that human interactive behavior is sequentially organized (Rohlfing et al., 2016). Accordingly, verbal and nonverbal behavior are co-constructed by the interaction partners and form a pattern. For example, with respect to the occurrence of maternal vocal behavior, some nonverbal framing was notable. Firstly, one pattern with a high confidence suggests an intrapersonal sequence of gazing at the infant, smiling and speaking. In contrast, another pattern suggests an interpersonal sequence of mother gazing at her infant, infant gazing back followed by vocal behavior of the mother. The analysis reveals patterns emerging between infants as young as 3-months-old infants and their mothers.

Discussion

The two presented approaches clearly show how the inclusion of multiple modalities is becoming increasingly attainable in quantitative terms and how it allows for a more elaborate description of young infants' communicative contributions. This is critical for the analyses of early interactions. By allowing for contingencies, dependencies and patterns to emerge from multiple resources, analyses using the principles of the above approaches can show how subtle turn-taking skills – previously attributed to older infants – can now be investigated in younger infants as well. Future research can focus on how multimodality leverages unimodal behavior.

One of the differences between the two approaches is that the CRQA seems to be more hypothesis driven, because a decision needs to be made beforehand about the pairs of modalities mapped against each other. Moreover, careful pairings of the coded categories across the modalities needs to be considered. The frequent pattern mining is a more exploratory analysis as the premises and conclusions emerge as a result of the analysis. For future research, visualization techniques as well as combinations with statistical tests will be desired.

Addressing multi-level attention-and-action co-ordination in (semi-)naturalistic child-caregiver-object interactions using qualitative and automated methods

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What does it take for children to collaboratively participate in joint social activities, as well as learn from their participation? How do infants, children and their caregivers co-ordinate their joint activities?

Different research fields have framed this problem in different ways and looked into and highlighted various forms of co-ordination: Research adopting a cognitive perspective has primarily framed co-ordination in joint activities as knowledge based visual joint attention, and the co-ordination of a sequence of discrete instrumental actions (mostly verbal, mosty in advance; e.g. Tomasello 2005). Other approaches highlighting bodily aspects and adopting e.g. dynamical systems tools explored and made visible rhythmic base level co-ordination (e.g. entrainment) and local contingencies. Ecological and dynamical systems approaches also look at how the actions of the participants practically drive interpersonal co-ordination (Yu & Smith 2013). Conversation and interaction analysis performed sequence analyses, investigating how communication is normatively organised and how specific communicative resources are used to achieve specific functions in a communicative interaction such as turn taking. In this poster we seek to explore, integrate, and understand how these forms of co-ordination play together over multiple time-scales in the orchestration of multiple modalities and strands of interactions

Drawing from 1) an observational longitudinal study accompanying infants and caregivers during their everyday routines at their homes during their first year and 2) from semi-naturalistic child-caregiver-object interactions staged in the lab, we present selected pattens of multi-modal action and attention co-ordination. In particular, we focus on action arcs, a key meso-level feature with beginning, climax, and resolution recurring in multiple activities.

We combine and integrate 1) qualitative micro-analysis transcribing and analyzing selected episodes frame-by-frame drawing from interaction and conversation analysis (Kaja, book sharing) with 2) automatically collected measures of gaze co-ordination using dual 3D gaze tracking in a common co-ordinate frame, an innovative solution to the “multiple shaky cam” problem of mobile dual eye-tracking (see also Yu & Smith). We introduce a novel visualization technique using enhanced reality overlays allowing us to seamlessly combine the automated gaze co-ordination measures with quantitative and qualitative micro-analytic coding in the same work-flow (LitenMover: Live Interaction Tracking: Eye aNd MOtion Visualized in Enhanced Reality).

Our methodology is aimed at characterizing (gaze) co-ordination patterns in selected episodes and interpreting them against the background of larger, meaningful multi-modal activity contexts. We conclude with raising the question of how these resulting co-ordination patterns are actually achieved by the participants (and objects and cultural "scripts") co-creating the interaction as it unfolds – and ask how this may be illuminated by perspectives from computational neurobiology such as dynamic field theory (Cisek & Kalaska 2010, Schöner & Thelen 2006).

Title: The Developing Frontal-Parietal Network: Novel Spatial Imitation Tasks Predict Activation in Young Children

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Objectives: The neural signature of visuo-spatial working memory (VSWM), the short-term ability to retain and manipulate information, is well characterized in school-aged children and adults by frontal-parietal activation that strengthens with development and memory load (i.e., the number of items to be remembered; Moriguchi & Hiraki, 2013). Due to the technical difficulties associated with studying young children using fMRI, knowledge of the neural basis of VSWM in preschoolers is limited. Functional near infrared spectroscopy (fNIRS) may be a suitable alternative. Due to a lack of standardization of WM measurement in fNIRS studies, prior findings have been mixed (Buss, Fox, Boas, & Spencer, 2014; Moriguchi & Hiraki, 2013). Imitation tasks have demonstrated the effects of memory load on performance in early childhood in behavioral studies (Barr et al., 2016). The purpose of this study is to examine VSWM in young children using imitation tasks and fNIRS.

Methods: In the present study, we collected fNIRS data, with a 60-channel system, from 4- to 8-year-olds (n = 11) during two multi-step spatial imitation tasks: one well-established (Subiaul et al., 2015, 2014) and one novel. An experimenter demonstrated a sequence of actions and then the child was tested. In the novel task, a small robot is manipulated to move its limbs. In the Spatial Sequencing Task (SST; Subiaul et al., 2015, 2014), an experimenter touches pictures in a predetermined sequence. We hypothesized that these tasks would activate frontal-parietal networks during the test phase due to the demands of holding multiple steps in mind.

Results: Memory load was manipulated by length of sequence (2 to 5 steps). All children perform well on the 2-step sequences, however at 4-steps, performance is more variable, with older children exhibiting better performance. There were age-related changes in activation as a function of memory load in both tasks. Older children exhibited greater load-dependent increases in activation in frontal-parietal regions: in the left parietal region during the Robots task, and in the left frontal region during SST. Data collection with 3- to 8-year-olds is ongoing.

Conclusion: These imitation tasks are feasible for use in fNIRS with young children, as they are rapidly acquired non-verbal tasks which allow for measurement during both observation and test phases. These tasks also allow for the adjustment of memory load. Understanding the neural mechanisms underlying the development of imitation and load-dependent VSWM in very young children has important implications for our understanding of the science of learning. In ongoing

data collection, children are participating in a videochat interaction condition, to examine the neural mechanisms underlying learning via video-mediated interactions.

Investigating children's preference-based learning of words and actions: a gaze-contingent paradigm

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For young children, multimodal information seems to be omnipresent in their surroundings: For example, communication with young children not only includes the linguistic modality in form of speech but also movements like the hopping of the rabbit. This multimodal input has been shown to support language learning (Gogate, Bahrick, & Watson, 2000; Werker, Cohen, Lloyd, Casalola, & Stager, 1998). According to dynamic approaches, multimodal input can help the child to learn from the environment but also provides the possibility for the child to alter their own learning experience through selective attention (Gogate, Walker-Andrews, & Bahrick, 2001; Hirsh-Pasek, Golinkoff, & Hollich, 2000). This interactive scenario can be influenced by the child's curiosity and preferences, which, in turn, will shape the child's learning behaviour. In the current study, we investigated children's preferences for either actions or words, and their learning behaviour based on their preference.

2- to 3-year-olds (N = 40) participated in a novel gaze-contingent paradigm that allowed them to choose between words and actions for two novel objects after a first training phase with familiar objects. Thus, the child could shape his or her learning experience based on the preference for one of the two modalities. In the following test phase, the two objects were presented side-by-side on screen in silence for 2.5 s (baseline phase). Then, the objects disappeared when in a prime phase, infants either hear the label for one of the objects (word-object trial) or see a hand performing one of the actions (action-object trial). Then, the objects reappeared on-screen for a further 2.5 s (test phase) to examine whether participants looked at the correct target object upon hearing the label.

Generalized linear mixed models and growth curve models show that children's preferences are highly individual and interact with their learning behaviour. That is, children who preferred verbal input also learned these words, whereas children preferring actions rather showed successful action recognition. Still, word recognition appeared to be stronger than action recognition. In addition, we will present data from adults (data collection is on-going) to compare potentially similar learning mechanisms in adulthood.

Thus, children's curiosity seems to drive their learning experience: In our study, their interest in one modality fosters learning in this modality and possibly neglects learning in the other modality due to the child's self-chosen, individual amount of exposure. This directly relates to children's curiosity-driven learning when interest guides information acquisition and thereby guides learning. In multimodal environments, children's preferences might help to structure the complex input into chunks that are compatible with the child's cognitive capacities in that moment. In addition, gaze-contingent eye-tracking paradigms allow us to recognise children as active learners, which will help us to step deeper into our understanding of children's learning behaviour in a complex world.

456 words

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Association between preterm medical risk and mother's social touch patterns: an exploratory study

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The absence of appropriate sensory stimulation has been associated to developmental delay in children and several studies have documented maternal touch as an important process that assists infant growth and development. Preterm children often need to stay in incubators and are deprived of touch stimulation they would receive otherwise. Many studies showed the benefits of tactile and kinesthetic contact in the health, motor, and cognitive development of preterm children and in the quality of parent-child relationship. Research on maternal touch and its benefits to the preterm children has been focused in the first months of the children life. So, less attention has been paid to the specificities of maternal touch later in infancy and the impact that preterm medical risk has on the mother's touch behavior. The objective of this study is to explore if there were differences in maternal social touch patterns, when they interact in play situations, with their preterm infants; preterm participant also varied in two levels of medical risk.

Ten mothers and their preterm children aged 12 months old were observed during three mother-child play tasks: free play with toys, free play without toys, and play with a challeging toy. The sample of preterm infants was constituted by 5 high medical risk infants and 5 low medical risk (as defined by their clinical files). A microanalytic system of coding social touch in mother-child interactions was developed using a transcription program (ELAN) and the Mother Touch Scale (Stepakoff, 1999; Stepakoff et al., 2007). The onset/offset of every maternal touch was coded and categorized in twenty-one types of touch behaviors, that were ordinalized in eleven categories from affectionate touch to high intensity intrusive touch. Each touch category was defined according the type of maternal touch, the touch intensity, and the location of maternal touch in the infant's body.

The results show subtle differences in mother's touch patterns. Mothers of low risk preterm children touch more often and for longer, using more diversified touch types in the free play without objects task (compared to the object exploration tasks). In this sample, the proportion and duration of maternal touch varied by infant's medical risk and by the play task: mothers of low medical risk preterm infants generally touch less and for less time in their children when they were performing object-oriented tasks than mothers of high risk preterm. In the free play task the mothers of low risk children touched more using more diverse types of touch than mothers of high risk preterm. The subtle differences found in this exploratory study could help both researchers and practitioners to better understand the specificities of the mother-high/low risk preterm infant interaction.

A Longitudinal Analysis of Naturalistic Posture Networks in Infancy

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The acquisition of locomotor skills extends the range of postures and behaviors previously available to infants, allowing them to move and explore their surroundings in newer, more complex ways. But, some postures may be mechanically or cognitively easier to perform in a given context, and the development of some postures may impact the production of other postures. We know little about how infants transition from one posture to another during play and across development. Thus, we aimed to investigate how infants position themselves and transition through various postures during naturalistic play sessions held from before creeping onset to walking onset.

Thirteen infants were observed biweekly in 10-minute laboratory free play sessions, from 6 to about 17 months. The room contained toys, a couch, and a small set of stairs. At the end of each session, we used Touwen's Group III Neurological Assessment Scale to identify the onset of hands-and-knees creeping and walking. We used The Observer XT to video-code infant postures continuously into 8 categories: laying down, sitting, on all fours, squatting/kneeling, creeping, standing/bending over, cruising, and stepping. We grouped our longitudinal data into 4 time periods based on locomotor skill, each containing 3 sessions: pre-creeping, novice creeping, experienced creeping/pre-walking, and walking. For each time period, we determined how often infants moved from one posture to another during play and mapped those data using Social Network Analysis and Visualization software. We used repeated measures ANOVA and Friedman tests to detect changes in the proportion of time spent in each posture, the number of transitions between postures, and the density and centrality of the posture networks.

Although sitting was the most commonly displayed posture, it declined significantly over the four time periods as new locomotor skills emerged ($p<.001$). With this reduction in sitting, we saw increases in the number of transitions between postures produced during play in each time period, predominately after the onset of creeping ($p<.001$). Over time, the network density between postures increased significantly as infants acquired creeping skill and experience (both $ps<.001$), but not walking ($p=.206$; see Figure 1 for example from one infant). Therefore, infants showed more ability to shift between their range of postures within sessions and as a function of locomotor development. At each locomotor level, infants also tended to use their postures in play differently, which led some postures to become more or less centrally utilized in posture transitions during play and in each time period (all $ps<.001$).

During play and across locomotor development, infants showed reductions in sitting, increases in how readily they transitioned between postures, and greater connectivity between all of their postures. This suggests that during play, infants exploit whatever full range of postures they have available at any developmental time. Infants tended to use some postures more than others to transition between postures, and their patterns of body positioning changed over time. Consistent with dynamic systems theory, these data suggest that larger-scale developments in locomotion are accompanied by moment-to-moment differences in how infants position their bodies during play.

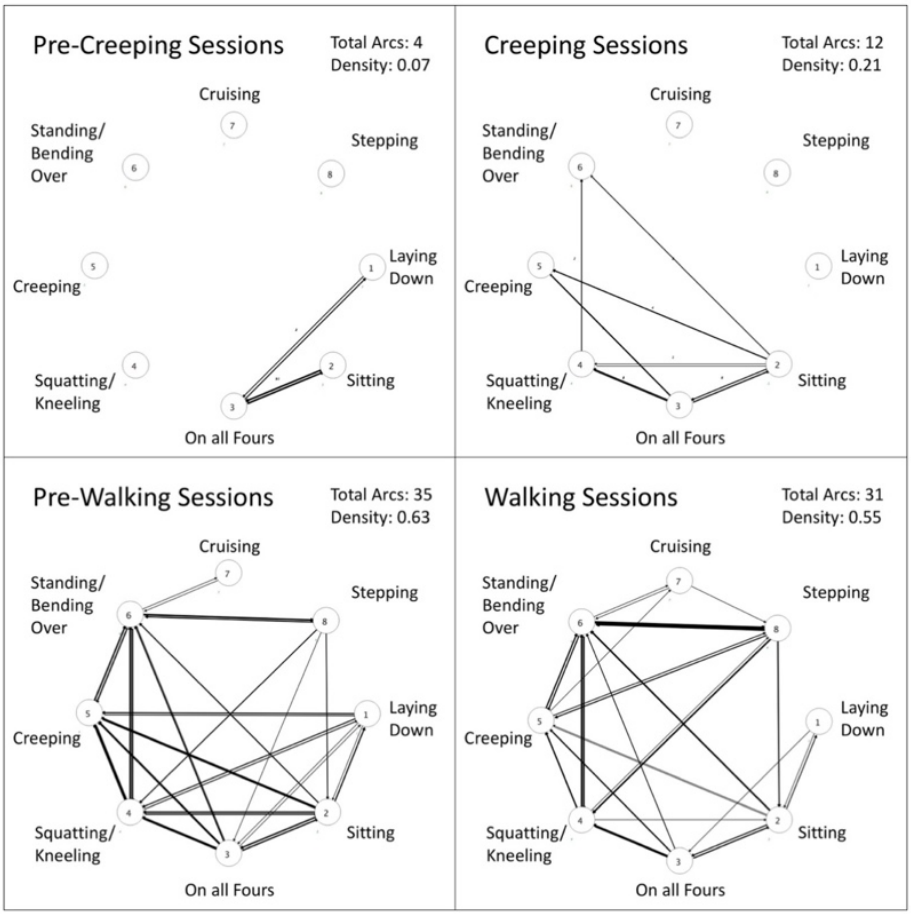

Figure 1. Example of posture networks for infant 01.

Dynamic interrelation of action perception and action production across the life span

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Successful social interaction is crucial for cooperation, joint action, and social learning. It depends on our ability to understand and predict others' actions. This perception of others' actions (*action perception*) is interrelated with the way we produce these actions ourselves (*action production*) and has previously been measured via children's and adults' anticipation of action goals. However, oculomotor abilities change across the life span. Therefore, action perception as operationalized via age-sensitive measures such as gaze latencies may not easily be compared across age groups. A more idiosyncratic measure of action perception is the characterisation of gaze behaviour time-series. Time-series analyses capture the complexity of the dynamics in behaviour and give insights into more subtle processes involved in action perception. The current study aimed at exploring the dynamics in action perception and their interrelation with action production across the human life span.

Participants between 3 and 80 years ($N = 214$) observed different multistep actions and then reproduced the according actions. Action production was assessed via the accuracy of this reproduction. Participants' action perception was measured via their anticipation of action goals during observation (using eye tracking). Additionally, we analysed the dynamics in gaze behaviour using recurrence quantification analysis (RQA) as one analysis technique of behavioural time-series. Specifically, we investigated whether certain states in gaze behaviour recurred over time and whether participants re-fixated previously fixated areas on the screen. Higher recurrence rates would indicate higher stability in gaze behaviour.

The findings show that action goals were anticipated more frequently with increasing age, $F(1,105) = 7.153$, $p = .009$, $R^2 = .064$. This measure of action perception was not related to participants' accuracy in action production ($\beta = 0.001$, $SE = 0.005$, $p = .848$). In contrast,

the RQA revealed that the recurrence in gaze behaviour was related to both, age and action production: Gaze behaviour was more recurrent (i.e. more stable) in very young and very old participants, $F(2,104) = 5.878$, $p = .004$, $R^2 = .010$ (Figure 1). Lower levels of recurrence were related to higher scores in action production across participants ($\beta = -0.000$, $SE = 0.000$, $p < .001$).

Incorporating a life-span perspective, this study illustrates the dynamic nature of developmental differences in the associations of action production with action perception. Furthermore, it proposes the analysis of time-series in gaze behavior as an alternative (and more informative) measure of action perception.

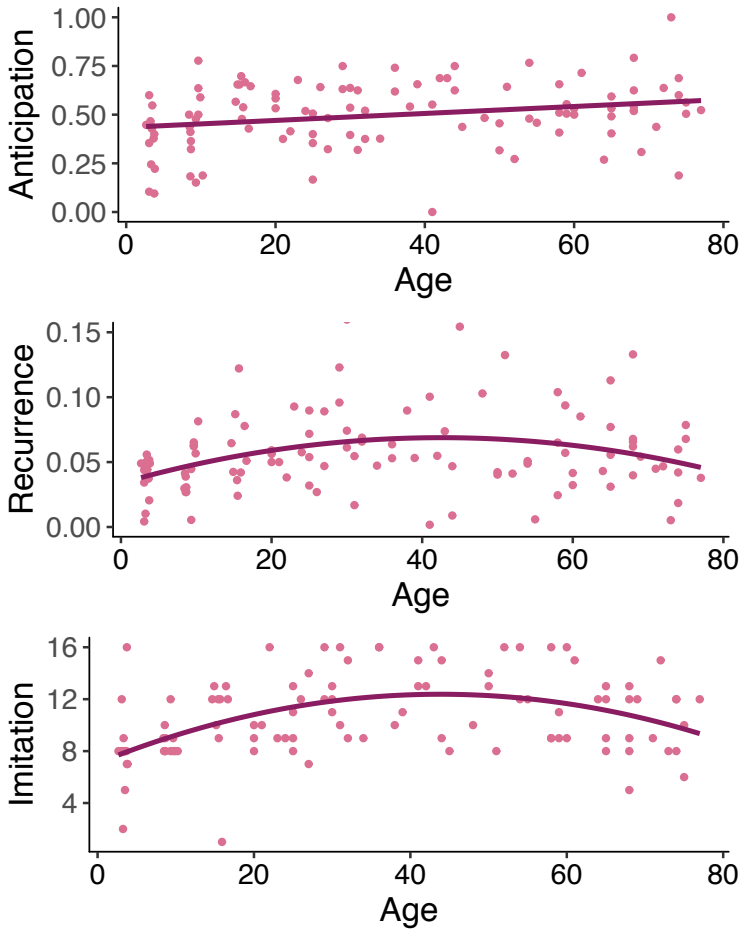

Figure 1. Anticipation frequencies, recurrence rates and imitation scores of participants across the life span.