Do preferences for words and actions influence word-object and action-object learning in
early childhood?

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Abstract

Children live in a multimodal world: For example, communication with young children not only includes information from the auditory linguistic modality in the form of speech but also from the visual modality in the form of actions that caregivers use in the interaction with children. Dynamic systems approaches suggest that multimodal input can help children to learn from the environment while also allowing the child to shape their own learning experience through selective attention. This selective attention might be influenced by the child's preferences, which, in turn, might shape the child's learning behaviour. In this study, we investigated how children's selective attention to information from the linguistic or the action modality influence learning in both domains.

Two- to 3-year-old children and adults participated in a novel gaze-contingent paradigm that allowed them to choose between being provided with the labels for or the actions that one can do with novel and familiar objects. At test, participants saw the two novel objects and either heard one of the labels or saw one of the actions that had been performed on one of the objects. Following label and action presentation, we investigated whether children fixated the target object, i.e., the object whose respective action/label had been presented, as an index of word and action learning. Children learned word but not action-object associations, and their target looking in the word-object condition was influenced by their selective attention to words in the earlier phase. Adults learned word-object associations and action-object associations, and their target looking in the action-object condition was influenced by their selective attention to actions in the earlier phase.

Gaze-contingent eye-tracking paradigms provide us a unique method to analyse children's active learning preferences, which will help us better understand children's learning behaviour in a complex world. In particular, we show that 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 the moment.

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Introduction

From early in life, children are exposed to a complex multimodal world. In such a rich environment, it may be helpful to filter the complex input available by selectively attending to relevant or pertinent information. However, what is perceived as relevant information may be influenced not only by salience, frequency, or other people’s focus, but also by our own log- or short-term individual preferences (i.e., subjective relevance). For example, if a child is presented with a frog that jumps around while the caregiver labels the frog, the child might attend either to the action or the word in the input and associate this with the object, the frog. Only when the perceptual abilities of the child meet the requirements to attend to and learn from both modalities in this scenario, might the child be able to learn both aspects. Until then, what the child learns might be a complex interaction of the child’s abilities and interests, and the immediate environment. Indeed, only once the cognitive and perceptual abilities of the child are sufficiently advanced (Eiteljoerge, Adam, Elsner, & Mani, 2019a, 2019b), might the child be able to simultaneously attend and learn from information from multiple modalities. Until then, what the child learns might be a complex interaction of the child’s abilities, interests, and the immediate environment.

The idea of an active, self-exploring child has had a long history in both theoretical and educational work in psychology (Montessori, 1914/1965, Piaget, 1936). It has been further formulated in dynamic systems theories that assume that no specific aspect of a situation is dominant per se, but it is rather the interaction between the child and her immediate environment which shapes the learning experience (Hirsh-Pasek, Golinkoff, & Hollich, 2000, Smith & Thelen, 1993). In such a theoretical framework, the child’s interests can direct the focus of her attention, and thereby influence the learning outcome (for a discussion on other theories and their contribution to active word learning, see Mani & Ackermann, 2018).

Indeed, the idea that children are actively engaged in learning has been supported in the recent years by many studies on children’s curiosity-driven learning and exploratory play. For example, Kidd and colleagues document the so-called Goldilocks effect, showing that even 7- to 8-month-olds chose what they attend to when presented with complex stimuli, avoiding both overly simple and complex scenarios with regards to their current state of knowledge (Kidd, Piantadosi, & Aslin, 2012, 2014). Further, using head-mounted cameras to examine attention to objects and caregivers in exploratory play, Yu and colleagues suggest that the perspective of the child’s egocentric view plays a crucial role in their early word learning (Smith, Jayaraman, Clerkin, & Yu, 2018, Yu & Smith, 2013). Later still, 3- to 5-year-olds appeared to learn better in an active touch screen task compared to their yoked control counterparts (e.g., Partridge, McGovern, Yung, & Kidd, 2015) and 6- to 8-year-olds showed improved memory in an object recognition game for actively compared to passively learned object locations (Ruggeri, Markant, Gureckis, & Xu, 2016). Nonetheless, this effect seems to be dependent on age (Kirkorian, Choi, & Pempek, 2016), and on other factors such as gender, socio-economic status, and the movements required to interact with a recording device (i.e., tapping or dragging, Russo-Johnson, Troseth, Duncan, & Mesghina, 2017). Relatedly, neurocomputational models show successful learning if the input and the current state of the learner are geared to one another, reflecting the changing dynamics that might be at work in infants’ learning (Twomey & Westermann, 2018).

This is not, however, to suggest that the exposure to language and communicative input that the child receives in her environment is unimportant. Language is acquired knowledge — thus what babies see and hear is critical to learning. Indeed, the amount and the quality of exposure to communicative interactions that children receive has long been shown to play a crucial role in early language acquisition, as Smolak and Weinraub (1983) suggested. In their study, mothers of highly verbal 2-year-old children produced more utterances as well as more words, and mirrored the child’s utterances more compared to mothers of less verbal 2-year-olds. Similarly, Huttenlocher, Haight, Bryk, Seltzer, and Lyons (1991) showed that vocabulary growth between 14 and 22

months depends crucially on the quantity of parental speech input. Taken together, learning here is characterized as a dynamic interaction between what the child selectively attends to in, ideally, an optimally rich environment.

In the current study, we focus on children’s early word and action learning. Infants as young as six months have been shown to discriminate familiar from unfamiliar actions (Hunnius & Bekkering, 2010) and to understand their first words (Bergelson & Swingley, 2013). But do they show improved learning of information from one domain over the other? Several studies have shown that children from the age of 30 months exhibit similar learning patterns when learning word- and action-object associations (Childers & Tomasello, 2002, 2003, Dysart, Mather, & Riggs, 2016, Riggs, Mather, Hyde, & Simpson, 2015). However, in these studies, children were presented separately with the novel word-object and action-object associations. There are few studies that have compared word-object and action-object learning when information from both domains is presented in the same context. For example, Hahn and Gershkoff-Stowe (2010) presented 4- to 5-year-olds with novel word-object and action-object associations in the same context and found that they learned both words and actions for objects (although they found better performance for actions than for words).

Another study investigated the development of children’s word- and action-object association learning by presenting 12-, 24- and 36-month-olds, as well as adults, with two novel objects which were presented with a novel label and a novel action. The following test phase measured their fixations to the target object upon hearing the label for this object or seeing the action that had previously been performed on this object. 12-month-olds learned action-object but not word-object associations, 24-month-olds learned neither word-object nor action-object associations, 36-month-olds learned word-object associations, and adults learned both word-object and action-object associations (Eiteljoerge et al., 2019b). These results highlight the developmental dynamics of early word and action learning with differences in children’s selective attention to different aspects of the signal potentially driving the differences in learning across development. The authors suggest that early in life children may prioritise

attention to actions due to the increased salience of these movements, while later on, with greater language exposure, they may attend more to linguistic input due to the communicative salience of this domain. While these differences in selective attention were explained at the group level at different ages, the current study examines whether individual differences in selective attention to different aspects of the input may yield a similarly diverse pattern of learning from the two domains. To examine this, we required a paradigm that would allow children to demonstrate their current preference for words versus actions in the input available to them. Gaze-contingent paradigms may provide one possible solution to this problem.

In gaze-contingent paradigms, the participant can actively trigger a stimulus change with her own eye gaze: While the participant's eye gaze is tracked, live calculations in the background allow for an immediate analysis of the participant's looking behaviour, which can then be used to display stimuli in a reactive manner by allowing continued fixations at pre-specified areas on the screen to trigger subsequent stimulus presentation. Reder (1973) provides one of the earliest systematic descriptions of gaze contingency, showing how this methodology could be used for studies exploring the participant's active participation and control monitoring in a task.

More recent work shows how this paradigm can provide insights into children's early anticipation behaviour. For example, Wang et al. (2012) presented 6- and 8-month-olds with a dot on one side of the screen. When participants fixated the dot, an image would appear on the other side of the screen. Their study showed that as early as three trials into the paradigm, infants learned to actively control the stimulus presentation and anticipated the according outcome. Further, Deligianni, Senju, Gergely, and Csibra (2011) showed that 8-month-olds would exhibit gaze following to a contingent non-human object suggesting that the reactivity in a situation, whether human or non-human, can lead to infants' responsive behaviour. Thus, from early on, infants' gaze can be used to control the presentation of stimuli such that the infant is an active participant in shaping her learning experience.

Current study

In the current study, we investigated how children's (and adults') preferences for input from one or the other domain can influence their learning outcomes in either domain. In a gaze-contingent eyetracking paradigm, participants could choose between hearing the label for or seeing an action being performed on the same object. For example, a child would consistently be presented with the label for the object if she looked to the image of the object presented on the left side of the screen, and see an action for the object if she looked to the image of the same object presented on the right of the screen.

In a first phase, all objects presented were highly frequent objects likely to be familiar to the participant. This allowed us to establish children's preference for information from either domain across a range of objects presented on-screen. In a second phase, the participants were presented with images of novel objects, and could again choose the information they were provided about these objects by looking at the image of this object either on the left or the image of the same object on the right side of the screen. This allowed children to control what they learned about particular objects since the amount of exposure they received in either domain was entirely contingent on where they looked during the trial. In a following non-gaze-contingent test phase, we examined children's learning and retention of the word- and action-object associations presented in the second gaze-contingent phase where they encountered the novel objects.

We hypothesised that children's learning of associations in both domains would depend on their preferences: a higher preference for information from one domain should result in better learning of this information in the novel association learning task. This would be in keeping with the literature on active learning described above suggesting that children follow their interests in selectively attending to their environment and retain information in keeping with these interests better. In contrast, we expected adults to learn information from both domains independent of any preferences they may have due to their potentially superior abilities to retain and

process complex information and their success in a similar task in previous studies (Eiteljoerge et al., 2019b).

We also examined children’s pupillary responses to violations of the associations they had been trained on, namely, violation of the actions performed on the different objects and violation of the kind of information presented on the different sides of the screen. We included the former test because 2- and 3-year-olds’ inability to recognize trained action-object associations in the previous literature (Eiteljoerge et al., 2019b) could either suggest that children did not form a strong association between the action and the object during the training phase or that children did not retain and store this association strongly enough to access it during test in a task where another recently familiar competitor object was concurrently presented. To tease these two explanations apart, we presented children with trials where they either saw the same action being performed on an object that they had previously been trained on (match trials), or saw the different (but equally familiar) action being performed on this object (mismatch trials). Increased pupillary dilation to mismatch trials due to the violation of their expectation of the action performed on this object could then be taken to suggest that children learned and retained the association but were unable to access this information in the context of the competitor object (Jackson & Sirois, 2009, Sirois & Jackson, 2012).

Second, we used an adapted version of this paradigm to test whether the participants associated information from one domain (e.g., words) with the side of the screen that information from this domain had been routinely presented on (e.g., left). Here participants saw two images of the same novel object on-screen. Fixations to a particular side of the screen triggered either the presentation of information from the domain that fixations to this side triggered in the earlier phases of the experiment (match trials), or the presentation of information from the other domain (mismatch trials). Increased pupillary dilation to mismatch trials would indicate that children had formed an association between the information domain and screen side during the previous trials and may have been sensitive to the fact that looks to different sides of the screen triggered different kinds of information.

Methods

Participants. Forty German monolingual 2- to 3-year-old children (range = 24;36 - 34;88 months; mean = 29;13, female = 22) and 26 adults (range = 19;34 - 32;07 years; mean = 24;19, female = 22) participated in the study. Additional participants were tested but excluded from the analysis during piloting (Children: 11), because of unwillingness to participate (Children: 4), technical failure (Children: 10, Adults: 1), preterm birth (Children: 3), experimenter error (Adults: 1) or insufficient data (Children: 9; Adults: 5, see Preprocessing). Children were recruited from the babylab database and participation was rewarded with a book. Adults were students of the University and were rewarded with 0.5 course credit points. Ethics approval was granted by the Ethics Committee of the Institute (Project 123).

Material. For the familiarisation phase, we used four familiar objects (a rabbit, a frog, a ball, and a plane), whose labels are typically familiar to children at the age of two (“Hase”, “Frosch”, “Ball”, and “Flugzeug”), and typical actions which can be performed on these objects (rabbit: hopping up and down, frog: hopping across the display, ball: bouncing, and plane: flying). We then created two types of videos: In the word videos, the label was presented in a carrier phrase (e.g., “Schau mal, ein Hase!” meaning “Look, a rabbit!”) with the stationary object on screen. In the action videos, the object was presented in silence while a hand performed the respective action on it.

For the word learning phase, we used the same material as in Eiteljoerge et al. (2019b). It included two novel germs (<https://www.giantmicrobes.com/us/>, see Fig. ??), two novel labels that adhere to German phonotactic rules (“Tanu” and “Löki”), and two novel actions (“moving up and down while tilting to the sides” and “moving sideways with back and forward leaning”). We again created two types of videos: In the word videos, the object was displayed as a still frame while the label was presented in a carrier phrase (e.g., “Schau mal, ein Tanu!” meaning “Look, a Tanu!”). In the action videos, the object was presented in silence while moving according to the assigned action. All videos were roughly seven seconds long, and both words and actions were

only presented once per video to match the exposure across domains (materials can be found on OSF under <https://osf.io/xeqb2/>).

Figure 1. Blue and yellow germ toys were used as novel objects. As novel actions, an upward movement with tilting to the sides (Panel A), and a sideways movement with tilting backwards and forwards (Panel B) were used.

For the test phase, we used pictures of the two objects in the baseline and the test phase. These pictures were 640×480 and presented in the center of the left and the right half of the screen. Thus, in a first baseline phase, the two pictures were presented on screen in silence. Then, in a prime phase, either a recording directed children to look at the one of the objects using its label “Where is the Tanu?” or a video presented a hand performing the action associated with one of the objects (without the object) was played. These prime videos were presented in the center of the screen and were roughly seven seconds long. In the test phase, both objects were presented on screen again in the same positions as before.

For the action violation phase, we used videos of the action presentation without any linguistic information. These videos were seven seconds long, and presented in the center of the screen. For the side violation phase, we used the same material and the same display as in the familiarisation phase. For the pupil dilation measure during both the action and the side violation phase, we used a 10 s video of bubbles that was stable in luminosity and kept the participants’ attention on screen, courtesy of Hepach, Vaish, and Tomasello (2012).

Procedure. Participants sat in a dimly lit and quiet experimental room at a distance of 65 cm from a TV screen (92×50 cm), where the visual stimuli were presented. A remote eye tracker (Tobii X 120, Manual, 2008), set on a platform

underneath the TV screen, was used to record gaze data at 60 Hz. Stimuli were presented using E-Prime software with the Tobii extension (Schneider, Eschman, & Zuccolotto, 2002). Auditory stimuli were presented through two loudspeakers above the screen. Further, two video cameras centered above the screen served to monitor the participant during the experiment. Prior to testing, gaze was calibrated using a 5-point calibration procedure, in which a red point appeared in every corner and the center of the screen. The calibration was checked using two pictures on the screen (a snail and a frog). Any systematic divergences in looking to the two pictures would lead to recalibration. After successful calibration, the experiment started with a fixation getter in the middle of the screen before each stimulus presentation.

Experimental design. All participants went through five different phases. The total length of the study depended on the participants (due to the gaze-contingent design) but usually took around ten minutes.

Gaze-contingent preference phase. The first eight trials of the experiment presented the participant with a still image of the same picture of a familiar object on the left and on the right side of the screen. When the participant looked at one of the two images, a frame in light gray would appear around this picture. If the participant then looked to the other side, this frame would follow to the other side. If the participant fixated one of the two images for 1000 ms, the other image would disappear and the chosen video would start to play. Importantly, one side was always associated with the same information content for individual participants (e.g., word video on the left side, action video on the right side). Thus, by fixating one side for at least 1000 ms, the participant could trigger the presentation of a video in the preferred domain. Eye blinks or short shifts initiated an additional counter. If the time period of looking away did not exceed 160 ms, counting towards the current fixation was continued. If it exceeded this time window, the counter for a fixation was reset. If the participant did not fixate any of the pictures for 15 s, the trial was aborted. This phase was meant to familiarise the participant with the gaze-contingent procedure, establish the side

association of word and action presentations, and measure the preference of the participant for either word or action presentations.

Gaze-contingent exposure phase. The gaze-contingent exposure phase presented the participant with the possibility to learn novel words and novel actions for novel objects. The presentation of the stimuli followed the same paradigm as in the preference phase. This time however, the participant was presented with still images of the novel objects. A fixation of 1000 ms to either the word or the action side would trigger the presentation of their novel labels or the corresponding actions performed on them, respectively. Children were presented with a total of 16 trials (eight per object), while adults were presented with a total of four trials (two per object).

Test phase. In eight following test trials, the two novel objects were presented side by side on screen in silence for 2.5 s (baseline phase). The objects disappeared after 2.5 s, triggering the beginning of a prime phase (similar to Von Holzen & Mani, 2012), during which participants either heard the label for one of the objects (Word-Object trial) or saw an empty hand performing one of the actions (Action-Object trial). 300 ms after the offset of the label or the end of the action, the objects reappeared on-screen for a further 2.5 s in the same positions as in the baseline phase (test phase). This test phase was identical to the test phase in the previous study on word and action learning (Eiteljoerge et al., 2019b).

Action violation phase. In four further trials, we examined alternative indices of participants’ action-object learning. Here, we presented participants with two match trials, in which the participants saw the novel objects and the previously associated actions (e.g., blue object moving up and down as in the exposure phase), followed by two mismatch trials in which the two objects were presented with the action (e.g., blue object moving to the side). Furthermore, a video of bubbles was presented before and after each trial, during which we measured tonic changes in pupil dilation (Hepach et al., 2012).

Gaze-contingent side violation phase. With the last four trials, we wanted to examine whether participants associated a particular type of information with a

particular side of the screen during the familiarisation phase. In other words, we wanted to examine here whether those participants who were always provided with word information on the left and action information on the right were sensitive to this assignment of side and information content. Such sensitivity would be key to any conclusions regarding participants' active manipulation of their learning experience. Thus, we presented participants with two side-match trials, where the word and action information were presented on the same side that they had been presented on during the familiarization phase, and two side-mismatch trials, where the word and action information were presented on the opposite side that they had been presented on during the familiarization phase. As above, a video of bubbles was presented before and after each trial for tonic measures of pupil dilation following side-match and side-mismatch trials.

Pre-processing. The eye-tracker provides an estimate of where participants were looking at during each time stamp of the trial, with one data point approximately every 16 ms. All data (gaze data and trial information) were exported from E-Prime and then further processed in R (R Core Team, 2016). For each time stamp, data were only included when one or both eyes of the participant were tracked reliably (validity less than 2 on E-Prime scale). When both eyes were tracked, the mean gaze point for both eyes was computed for further analysis. Gaze data were then aggregated into 40 ms bins. Areas of interest identical in size to one another were defined based on the size and location of the videos and images on screen. For the test phase, we coded whether the participant looked at the correct object (i.e., the target), the distractor or at neither of these onscreen. Typically, fixation data is analysed from 240 ms to 2000 ms from the onset of a label (see also Swingley, Pinto, & Fernald, 1999), since only these fixations can be reliably construed as a response to an auditory stimulus. Following this convention, we analysed the data from 240 ms from the onset of the baseline phase. This ensured that we avoided early fluctuations in fixations as a result of the images appearing on-screen. Furthermore, we corrected the test phase for any preferences in

the baseline phase on an individual trial level (i.e., each time point in the test phase was corrected for the overall looking score in the baseline phase on that particular trial).

For the pupil dilation measure, only timestamps providing valid eyetracking data were included in the analysis. We used a threshold filter for both pupils separately, that excluded data points in which the difference between two adjacent data points fell into the top ten percent of overall differences between adjacent time points. This procedure ensures that large deviations between adjacent samples are excluded which are often artefacts in the data. Further, data were interpolated with a sample size of four to account for gaps due to missing data (Hepach et al., 2012). Finally, data from both eyes were averaged.

To ensure good data quality, we used specific exclusion criteria. Participants who did not trigger at least one action or word video in the entire gaze-contingent preference phase were excluded from the study as we could not be sure that these participants had understood the study design (C: $n = 8$, A: $n = 3$), since they had never seen the other information that could be provided. Further, one participant who did not trigger any content in any of the videos was excluded (A: $n = 1$). Also, single test trials were excluded if a participant was looking at the stimuli more or less than $M \pm 3SD$ of the time. Thus, a trial was excluded if a child looked less than 52.13 % of the time during the trial to one of the two pictures. This led to an exclusion of 20 trials (7.69 %). For adults, this criterion was at ≤ 38.93 %, 15 trials (7.58 %). This led to another exclusion as the participant did not look enough during any of the trials (A: $N = 1$).

Furthermore, participants were excluded if they contributed trials in only one of the two conditions (C: $N = 1$). Finally, it was ensured that participants contributed more than one trial per condition in the test phase and that there were no missing data in either the Baseline or the Test phase in one of the conditions. This did not lead to further exclusions, and thus, left us with 66 participants overall.

Results

First, we present the analysis of target fixations during the test trial to examine whether participants had learned the word-object and action-object associations presented, and how their learning interacted with their choices in the preference phase. Then, we present the analysis of the action violation and the side violation phase. Finally, we present an exploratory analysis testing whether participants continued their preference during the familiarisation phase during the learning phase, or whether they changed their information sampling method when presented with new information in the learning phase.

The influence of preference on learning. In this section, we first report analyses of all age groups together, then split the data according to age, and by condition to test whether each age group learned in both of the conditions and whether there are differences between conditions. For each analysis, we report two statistical approaches. First, we report traditional t-tests and correlations. Then, we report generalized linear mixed models controlling for additional factors such as object, name, action, and exposure, which also allows us to include the factor *Time* during the trial. Our aim here is not to compare the characteristics of the individual types of analyses, but rather to ensure that the findings we report converge when using both statistical approaches.

We used generalised linear mixed models (GLMM) to analyse how participants' proportional target looking unfolded over the entire time course of the test phase (also called growth curve models; for a more detailed description and instruction see Mirman, 2016, Mirman, Dixon, & Magnuson, 2008). Were participants to not recognize the target, they ought to fixate both the target and distractor equally throughout the time course of the trial, with their fixations at chance altogether. Were participants to recognize the target, their fixations to the target should increase from chance level during the trial, and return towards chance level towards the end of the trial (mirroring a quadratic curve, or a quartic curve when considering tails). In practice, adults usually fixate the target until the end of the trial (e.g., Mirman et al., 2008), while children's

target looking appears to increase later during the trial, and is often weaker and more variable throughout the trial (see Eiteljoerge et al., 2019b, for a more elaborate description).

We fitted a generalized mixed model using lme4’s lmer function in R (Bates, Maechler, Bolker, Walker, et al., 2014) with Gaussian error structure and identity link function. For all models, participant id, label (Tanu, Löki), object colour (blue object, yellow object), and action (up, side) were included as random effects. Age at test, preference, and exposure were z-transformed (to a mean of zero and a standard deviation of one) to simplify later interpretation across groups. The exact models for each analysis can be seen below.

We highlight here a difference in our calculations from the gaze-contingent preference and the gaze-contingent exposure phase. We refer to the choices made by participants in the preference phase as their preference for actions versus word information associated with objects in general. We refer to the choices made by participants during the exposure phase as exposure, since these choices determined the number of word and action trials participants saw, training them on the novel word-object and action-object associations, respectively. While it is likely that preference and exposure thus defined are related to one another, we use this notation to differentiate between the two phases and to motivate some of the analyses that follow. For each phase and each domain, we calculated the overall number of trials chosen in that domain.

We also included *Time* and its second, and third polynomial in the model. This allowed us to model our data as a linear, quadratic, and cubic function of time, and thus, to capture according shapes in the data (the number of polynomials has been restricted to four based on theoretical considerations regarding looking behaviour). We used the function *drop1* to evaluate the influence of each factor in the model. This function compares the model including one factor with a model without this factor, and thereby evaluates its contribution to the model. An overview of the results can be seen in Tab. 3, Tab. 4, Tab. 5, and Fig. 2, Fig. 3, and Fig. 4.

Both age groups. We first run a linear mixed model to evaluate influences of condition and age on target looking. The model revealed a main effect of Condition, $\chi^2 = 8.26$, $df = 1$, $p = .004$, and a main effect of Age, $\chi^2 = 13.32$, $df = 1$, $p < .001$.

These results suggest differences across age groups and across conditions (see Fig. 2). We then split the data according to age group.

Figure 2. Time course graphs for participants' baseline-corrected proportional target looking (PTL) in the Word-Object and the Action-Object condition during the test phase after label onset and 233 ms to initiate a fixation. The line at 0 represents chance level, looks above the line reflect proportionally more target looking and looks below the line reflect distractor looking.

2- to 3-year-olds. We ran a linear mixed model to test the effect of condition on target looking. The model revealed a main effect of Condition, $\chi^2 = 4.4$, $df = 1$, $p = .036$, with higher proportional target looking in the word compared to the action condition.

Then, we split the data according to condition and added the preference and exposure for the respective condition to the model. Thus, for the word-only model, we analysed the influence of word preferences and word exposure on target looking, while

for the action-only model, we analysed the influence of action preferences and action exposure on target looking.

For the word-only model, the model revealed a significant effect on the intercept ($p = .005$), indicating that children’s target looking in the word-object condition differed from chance. For the action-only model, none of the factors were significant, indicating that children’s target looking in the action-object condition did not differ from chance.

These results suggest that 2- to 3-year-old children learned to associate words with objects but not actions with objects, and word and action preferences did not influence their target recognition in the two domains.

To evaluate how participants’ choices in the preference phase influenced the time course of participants’ target looking, we run exactly the same models as the previous ones that included preferences and exposure separately for each condition, and additionally included polynomials up to the cubic term and their interaction with the preference score.

Using drop1, the word-only model revealed a significant interaction of word preference*poly3 ($\chi^2 = 6$, $df = 1$, $p = .014$). The action-only model revealed no significant interactions between preference and polys, indicating that children’s time course of target looking in the action-object condition did change with their level of action preference.

Thus, on the group level, 2- to 3-year-old children showed a difference between word and action learning, with proportionally more target looks in the word-object than in the action-object condition. Furthermore, they learned to associate words but not actions with objects. On an individual level, preferences influenced target looking in the word-object but not in the action-object condition. Children with a high word preference showed a cubic curve that increased from chance level and returned to chance level towards the end of the trial. Children with a low word preference showed a steady increase in target looking throughout the trial (see Fig. 3).

Figure 3. Time course graphs for 2- to 3-year-olds’ baseline-corrected proportional target looking (PTL) in the Word-Object condition during the test phase after label onset and 233 ms to initiate a fixation. For visualisation purposes, data were split according to the median of word preference. A high word preference is represented in yellow, a low word preference is in blue. The line at 0 represents chance level, looks above the line reflect proportionally more target looking and looks below the line reflect distractor looking.

Adults. We ran a linear mixed model to test the effect of condition on target looking. The model revealed a main effect of Condition, $\chi^2 = 4.11$, $df = 1$, $p = .043$, with higher proportional target looking in the word than in the action condition.

Then, we split the data according to condition and added the preference and exposure for the respective condition to the model. Thus, for the word-only model, we analysed the influence of word preferences and word exposure on target looking, while for the action-only model, we analysed the influence of action preferences and action exposure on target looking.

For the word-only model, the model revealed a significant effect on the intercept ($p < .001$), indicating that target looking in the word-object condition differed from chance. Also for the action-only model, the model revealed a significant effect on the

intercept ($p = .001$), indicating that target looking in the action-object condition differed from chance.

These results suggest that adults learned to associate words and actions with objects, and word and action preferences did not influence their overall target looking in the two domains.

To evaluate how participants' choices in the preference phase influenced the time course of participants' target looking, we run exactly the same models as the previous ones that included preferences and exposure separately for each condition, and additionally included polynomials up to the cubic term and their interaction with the preference score.

Using drop1, the word-only model revealed no significant interactions between word preference and the polys, indicating that the time course of target looking did not change significantly with their preference. The action-only model revealed a significant interaction of action preference*poly3 ($\chi^2 = 4.46$, $df = 1$, $p = .035$), indicating that the time course of target looking changed with their action preference.

Thus, on the group level, adults showed a difference between word and action learning, with proportionally more target looks in the word-object than in the action-object condition. Furthermore, they learned to associate words and actions with objects. On an individual level, preferences influenced target looking in the action-object but not in the word-object condition. Adults with a high action preference showed a high plateau of target looking throughout the trial. Adults with a low action preference showed a cubic curve of target looking: Their time course of target looking showed a slower increase and a lower plateau compared to adults with a high action preference (see Fig. 4).

Action violation. In the action violation phase, we tested whether participants were sensitive to a change in the action that was performed on the object. As a measure, we used participants' pupil dilation during the bubbles videos (Hepach et al., 2012) which were presented between the stimuli videos. As a baseline, we used the first bubbles video that was presented before any of the action videos. For the match trials,

Figure 4. Time course graphs for adults’ baseline-corrected proportional target looking (PTL) in the Action-Object condition during the test phase after label onset and 233 ms to initiate a fixation. For visualisation purposes, data were split according to the median of action preference. A high action preference is represented in yellow, a low action preference is in blue. The line at 0 represents chance level, looks above the line reflect proportionally more target looking and looks below the line reflect distractor looking.

we then used the second and third presentation of bubbles that each followed after one of the videos that presented a matching action. For the mismatch trials, we then used the fourth and fifth presentation of bubbles that each followed after one of the videos that presented a mismatching action.

First, we report t-tests comparing match trials vs. baseline and mismatch trials vs. baseline. Then, we report linear mixed models that evaluate the change of pupil dilation in mismatch trials against chance level (chance = 0), while controlling for participants’ pupil dilation in the match trials. This was done to incorporate any carry-over effects from the match trials due to the fixed order of match-mismatch trials. To account for basic behaviours of the pupil in later trials, we baseline-corrected both match (match - baseline) and mismatch trials (mismatch - baseline). With regard to the models, an effect on the intercept would suggest a difference between the averaged

minimum pupil dilation in mismatch trials and chance, while an effect of match trials would indicate an additional influence of match trials. Note that χ^2 statistics are not available for intercept statistics, because χ^2 is a measure based on model comparison. A model without an intercept is impossible, and therefore, there is no model comparison available.

Before the analysis, we ensured that each participant contributed data in the first and second window of baseline, match, and mismatch. Thus, for the following analyses, we could include 28 children and 22 adults.

Table 1

Minima of pupil dilation in the action violation phase for 2- to 3-year-olds and adults.

Age	Baseline	Match	Mismatch
Children	2.11	2.11	2.25
Adults	3.10	2.95	2.55

2- to 3-year-olds. For the 2- to 3-year-olds, a paired t-test between mismatch and baseline trials was significant ($t(27) = -2.28$, $p = .031$, $d = -0.61$), indicating an increase in pupil dilation in the mismatch trials compared to baseline. The comparison between match and baseline trials was not significant ($t(27) = -1.44$, $p = .160$, $d = -0.39$).

The model comparing pupil dilation in mismatch trials to chance while controlling for pupil dilation in match trials revealed a significant effect of pupil dilation in the mismatch trials on the intercept ($p = .01$) and of match trials ($\chi^2 = 10.53$, $df = 1$, $p = .001$). Pupil dilation was significantly above chance in mismatch trials, and larger pupil size in match trials was related to larger pupil size in mismatch trials.

The increase in pupil dilation from chance level in mismatch trials suggests that 2- to 3-year-old children were sensitive to the action violation.

Adults. For the adults, a paired t-test between match and baseline trials was significant ($t(21) = 3.41$, $p = .003$, $d = 1.03$), as was the comparison between mismatch and baseline trials ($t(21) = 2.35$, $p = .028$, $d = 0.71$), indicating a decrease in pupil dilation in both match and mismatch trials compared to baseline.

The model comparing pupil dilation in mismatch trials to chance while controlling for pupil dilation in match trials revealed a significant effect of pupil dilation in the mismatch trials on the intercept ($p = .023$), and a significant effect of match trials ($\chi^2 = 16.8$, $df = 1$, $p < .001$). Pupil dilation was significantly below chance in mismatch trials, and larger pupil size in match trials was related to larger pupil size in mismatch trials.

The decrease in pupil dilation from chance level in mismatch trials suggests that adults might have shown symptoms of disengagement and fatigue during the task (Hopstaken, van der Linden, Bakker, & Kompier, 2015).

Side violation. In the side violation phase, we tested whether participants associated one type of content (i.e., words) with one side of the screen (i.e., left) during the preference phase, and would therefore be sensitive to a violation in the presentation (i.e., words presented on the right). Again, we used the bubbles video and participants' change in pupil dilation to test this aspect, and we report the same analyses as in the section above.

Before the analysis, we ensured that each participant contributed data in the first and second window of baseline, match, and mismatch. Thus, for the following analyses, we could include 32 children and 25 adults.

Table 2

Minima of pupil dilation in the side violation phase for 2- to 3-year-olds and adults.

Age	Baseline	Match	Mismatch
Children	2.44	1.97	2.48
Adults	2.96	2.99	2.07

2- to 3-year-olds. For the 2- to 3-year-olds, a paired t-test between match and baseline trials was significant ($t(31) = 2.17$, $p = .038$, $d = 0.54$), indicating a decrease in pupil dilation from baseline to match trials. Further, a paired t-test between match and baseline trials was significant ($t(31) = 3.24$, $p = .003$, $d = 0.81$), indicating an increase in pupil dilation from baseline to mismatch trials.

The model comparing pupil dilation in mismatch trials to chance while controlling for pupil dilation in match trials only revealed a significant effect of match trials ($\chi^2 = 22$, $df = 1$, $p < .001$). Pupil dilation was not significantly different from chance in

mismatch trials, and larger pupil size in match trials was related to larger pupil size in mismatch trials.

These results suggest that children were not sensitive to the side violation.

Adults. For the adults, a paired t-test between match and baseline trials was not significant ($t(24) = 1.86$, $p = .076$, $d = 0.52$), and neither was the comparison between match and baseline trials ($t(24) = 0.76$, $p = .45$, $d = 0.22$), indicating that the pupil size did not change significantly across trial types.

The model comparing pupil dilation in mismatch trials to chance while controlling for pupil dilation in match trials revealed only a significant effect of match trials ($\chi = 8.02$, $df = 1$, $p = .005$). Pupil dilation was not significantly different from chance in mismatch trials, and larger pupil size in match trials was related to larger pupil size in mismatch trials.

These results suggest that adults were not sensitive to the side violation.

Further exploratory analysis. To investigate whether preference and exposure choices aligned for children and adults, we correlated these two measures (Fig. 5). For the 2- to 3-year-olds, preference and exposure choices were positively correlated for words ($r(40) = .61$, $p < .001$) and for actions ($r(40) = -.55$, $p < .001$), meaning that higher preference values in one domain meant higher exposure values in the same domain. For adults, both correlations were not significant.

Discussion

In the current study, we investigated the influence of preference on learning of word-object and action-object associations in 2- to 3-year-old children and adults using a gaze-contingent paradigm. In a first gaze-contingent preference phase, participant could choose with their gaze whether they wanted to hear a familiar label or see a familiar action for a familiar object. In the following gaze-contingent exposure phase, participants could again choose whether they wanted to hear a novel label or see a novel action for a novel object. Afterwards, their learning of the presented word-object and action-object associations was tested in a preferential looking paradigm. We found that

Figure 5. Correlation of word and action choices in the preference and the exposure phase for 2- to 3-year-olds and adults. Note that the exposure score has been z-transformed to allow for comparisons across groups.

children at this age learned word-object but not action-object associations, replicating our previous findings (Eiteljoerge et al., 2019b). Further, children’s preferences influenced target looking in the word-object condition but not in the action-object condition. Adults’ preferences influenced target looking in the action-object condition but not in the word-object condition.

Our results on children’s word and action learning are in line with our previous study in which we found that 3-year-olds would learn word-object but not action-object associations (Eiteljoerge et al., 2019b). We extended these results showing how children’s individual preferences can modulate their behaviour, and found that only their target looking in the word-object condition, but not in the action-object condition, was modulated by their preferences. Children with a high word preference showed an increase in target looking from chance level in the beginning of the trial, which decreased towards the end of the trial, whereas children with a low word preference showed a steady increase in target looking throughout the trial. Thus, the pattern of

target looking in the children with a high word preference resembles a pattern that would be expected on a theoretical level (as outlined above), and might therefore be taken as evidence for children’s successful target recognition in word-object test trials. For children with a low word preference, their target looking appears to increase later. Nonetheless, it is important to note that, overall, children between two and three years of age learned words for objects successfully. These observations were mirrored in the action-object condition for the adults: They learned action-object associations, but their target looking at test followed different trajectories with differences in preference. Adults with a high action preference showed a high plateau throughout the trial, while adults with a low action preference showed a slower increase with a lower plateau. Both patterns are indicative of adults’ action-object association learning, and expected given adults’ typical target looking behaviour (Mirman et al., 2008). Together, these findings can be taken as support for the conclusions by Wade and Kidd (2019) who suggest that curiosity may contribute to learning, but its contribution is limited: In our setting, preferences appeared to change the response behaviour but did not change the overall learning pattern.

The influences of preference on target looking differed from our expectations in the two age groups. While we expected an influence in both domains for children, we expected no influence for adults. One possible explanation for the diverging results might be the relation between curiosity and participants’ certainty in knowing an association. Adults’ target looking in the word-object condition was overall high and appeared to have little variance, adults’ target looking in the action-object condition and children’s target looking in the word-object condition appeared to have high variance, whereas children’s target looking in the action-object condition was overall around chance level and appeared to have little variance. If we take variance as an indicator of certainty, then increased variance in the data might be a sign for higher uncertainty. Accordingly, in scenarios with high variability, preferences might have stronger influences on behaviour compared to scenarios where uncertainty is low,

because such preferences might help to reduce uncertainty during information processing (Gottlieb, Oudeyer, Lopes, & Baranes, 2013).

The influence of preference on participants' target recognition reflects how characteristics of the learner contribute to learning: In terms of dynamic systems accounts, this reflects the interactive nature of the organism and the environment (e.g., Smith & Thelen, 1993). While the environment provides information (e.g., in form of words and actions for objects), the learner's preferences play an active role in the processing of information. In this way, the learner can focus on specific aspects of the input, which in turn helps them to reduce the information to be processed (Kidd & Hayden, 2015).

In contrast to children's word-object association learning results, we did not find evidence for children's learning of action-object associations which is in line with our previous results (Eiteljoerge et al., 2019b). In the current setting, action-object learning might have been impeded additionally by the interleaved presentation of these associations that resulted from children's choices in the exposure phase. This could result in large gaps between the same input, and thereby impede learning of a certain mapping at this age. Accordingly, blocking the presentation of the associations might simplify learning of the associations in the current setting (Mather & Plunkett, 2011). Older children who have been shown to learn both words and actions for objects (e.g., Hahn & Gershkoff-Stowe, 2010) might show action-object association learning because of their further developed perceptual abilities. The absence of an influence of preference in the action-object condition could be due to the smaller amount of variance in this condition as described above: if most children did not show action-object learning at all, any preferences might have little effects on target looking modulations. Thus, if older children learn the action-object associations, any potential influences of preferences on learning might then surface.

Although children did not show target recognition in the action-object condition at test, they seemed to discriminate between match and mismatch trials in the action violation phase, as indicated by an increase in pupil dilation. This suggests that they

were able to recognize a change in the action-object association despite not storing this information for longer. This is in contrast to adults, who showed successful learning of action-object associations in the test phase, but showed a decrease in pupil dilation as a reaction to the action violation. These results potentially shed light on the different nature of recognition and learning (McMurray, 2016). For children, recognising a change in action-object associations might involve low processing demands while recalling them in the test phase later in the experiment might have required more efforts to store the mapping for longer. For adults however, learning an action-object association might be less demanding. In addition, adults might be more tolerant regarding different actions for the same object based on their experience: in contrast to many word mappings, action mappings are often not necessarily one-to-one mappings. Accordingly, they might rather show symptoms of disengagement and fatigue (Hopstaken et al., 2015) instead of an increase in pupil dilation which could reflect the violation of an expectation (Satterthwaite et al., 2007).

For our gaze-contingent paradigm to work, it was important that participants recognized that each side of the screen was associated with one type of information. However, both age groups did not show any changes in pupil dilation after the mismatch trials. These results could indicate that participants did not associate one type of content with one side of the screen. The positive correlation between the preference and the exposure phase suggest a systematic pattern in children’s choices which could be taken as indirect evidence for their recognition of the side association. However, these results could also reflect a side preference that was present in children but not adults. Although we coined participants’ behaviour as *choice* indicating a *preference* throughout the manuscript, these results might also support a leaner interpretation of their behaviour in terms of selective attention to the information presented or a side preference in the case of children. We asked some adults after the experiment whether they noticed something, and they often mentioned that they figured out that they could choose with their gaze which could be taken as anecdotal evidence for adults’ awareness of their choice during the preference and exposure phase.

However, participants' awareness of the functioning of the paradigm and the underlying mechanisms during such gaze-contingent study designs still require substantial investigation. If we can confirm in future studies that participants are aware of their choices and indeed choose according to their preference, such gaze-contingent designs could be an interesting avenue for research that tries to bridge highly controlled experimental settings and purely observational tasks, allowing for many more research questions that address the interactions between the learner and the environment.

To conclude, we found that 2- to 3-year-old children learned words but not actions for objects, and that their preferences influenced target looking in the word-object but not in the action-object condition. But although they did not show action-object association learning at test, they were sensitive to a change in action-object mappings, suggesting that they remembered action-object mappings from one trial to the next. Further, we found that adults learned words and actions for objects, and their preferences influenced target looking in the action-object but not in the word-object condition. Overall, this research contributes to the growing literature on how children's own characteristics like their preferences can influence their behaviour, and how this influence changes with development.

References

- Bates, D., Maechler, M., Bolker, B., Walker, S., et al. (2014). lme4: Linear mixed-effects models using eigen and s4. *R package version, 1*(7), 1–23.
- Bergelson, E., & Swingley, D. (2013). The acquisition of abstract words by young infants. *Cognition, 127*(3), 391–397. doi: 10.1016/j.cognition.2013.02.011
- Childers, J. B., & Tomasello, M. (2002). Two-year-olds learn novel nouns, verbs, and conventional actions from massed or distributed exposures. *Developmental Psychology, 38*(6), 967.
- Childers, J. B., & Tomasello, M. (2003). Children extend both words and non-verbal actions to novel exemplars. *Developmental Science, 6*(2), 185–190.
- Deligianni, F., Senju, A., Gergely, G., & Csibra, G. (2011). Automated gaze-contingent objects elicit orientation following in 8-month-old infants. *Developmental Psychology, 47*(6), 1499–1503. doi: 10.1037/a0025659
- Dysart, E. L., Mather, E., & Riggs, K. J. (2016). Young children’s referent selection is guided by novelty for both words and actions. *Journal of Experimental Child Psychology, 146*, 231–237.
- Eiteljoerge, S., Adam, M., Elsner, B., & Mani, N. (2019a). Consistency of co-occurring actions influences young children’s word learning. *Royal Society open science, 6*(8), 190097. doi: 10.1098/rsos.190097
- Eiteljoerge, S., Adam, M., Elsner, B., & Mani, N. (2019b). Word-object and action-object association learning across early development. *PloS One, 14*(8), e0220317. doi: 10.1371/journal.pone.0220317
- Gottlieb, J., Oudeyer, P.-Y., Lopes, M., & Baranes, A. (2013). Information-seeking, curiosity, and attention: computational and neural mechanisms. *Trends in Cognitive Sciences, 17*(11), 585–593.
- Hahn, E. R., & Gershkoff-Stowe, L. (2010). Children and adults learn actions for objects more readily than labels. *Language Learning and Development, 6*(4), 283–308. doi: 10.1080/15475441003635315
- Hepach, R., Vaish, A., & Tomasello, M. (2012). Young children are intrinsically

- motivated to see others helped. *Psychological Science*, 23(9), 967–972.
- Hirsh-Pasek, K., Golinkoff, R. M., & Hollich, G. (2000). An emergentist coalition model for word learning. In *Becoming a word learner: A debate on lexical acquisition* (pp. 136–164). Oxford, UK: Oxford University Press. doi: 10.1093/acprof:oso/9780195130324.003.006
- Hopstaken, J. F., van der Linden, D., Bakker, A. B., & Kompier, M. A. (2015). The window of my eyes: Task disengagement and mental fatigue covary with pupil dynamics. *Biological psychology*, 110, 100–106. doi: 10.1016/j.biopsycho.2015.06.013
- Hunnius, S., & Bekkering, H. (2010). The early development of object knowledge: A study of infants’ visual anticipations during action observation. *Developmental Psychology*, 46(2), 446–454. doi: 10.1037/a0016543
- Huttenlocher, J., Haight, W., Bryk, A., Seltzer, M., & Lyons, T. (1991). Early vocabulary growth: relation to language input and gender. *Developmental Psychology*, 27(2), 236.
- Jackson, I., & Sirois, S. (2009). Infant cognition: going full factorial with pupil dilation. *Developmental Science*, 12(4), 670–679.
- Kidd, C., & Hayden, B. Y. (2015). The psychology and neuroscience of curiosity. *Neuron*, 88(3), 449–460.
- Kidd, C., Piantadosi, S. T., & Aslin, R. N. (2012). The goldilocks effect: Human infants allocate attention to visual sequences that are neither too simple nor too complex. *PLoS ONE*, 7(5), e36399. doi: 10.1371/journal.pone.0036399
- Kidd, C., Piantadosi, S. T., & Aslin, R. N. (2014). The goldilocks effect in infant auditory attention. *Child Development*, 85(5), 1795–1804. doi: 10.1111/cdev.12263
- Kirkorian, H. L., Choi, K., & Pempek, T. A. (2016). Toddlers’ word learning from contingent and noncontingent video on touch screens. *Child Development*, 87(2), 405–413.
- Mani, N., & Ackermann, L. (2018). Why do children learn the words they do? *Child*

- Development Perspectives*. doi: 10.1111/cdep.12295
- Manual, U. (2008). *Tobii x60 and x120 eye-trackers*. Tobii.
- Mather, E., & Plunkett, K. (2011). Same items, different order: Effects of temporal variability on infant categorization. *Cognition*, 119(3), 438–447.
- McMurray, B. (2016). Language at three timescales: The role of real-time processes in language development and evolution. *Topics in cognitive science*, 8(2), 393–407.
- Mirman, D. (2016). *Growth curve analysis and visualization using r*. CRC Press.
- Mirman, D., Dixon, J. A., & Magnuson, J. S. (2008). Statistical and computational models of the visual world paradigm: Growth curves and individual differences. *Journal of Memory and Language*, 59(4), 475–494. doi: 10.1016/j.jml.2007.11.006
- Montessori, M. (1914/1965). *Dr. montessori's own handbook*. New York, NY: Schocken.
- Partridge, E., McGovern, M. G., Yung, A., & Kidd, C. (2015). Young children's self-directed information gathering on touchscreens. In *Proceedings of the 37th annual conference of the cognitive science society*.
- Piaget, J. (1936). *Origins of intelligence in the child*. London: Routledge & Kegan Pau.
- R Core Team. (2016). R: A language and environment for statistical computing [Computer software manual]. Vienna, Austria. Retrieved from <https://www.R-project.org/>
- Reder, S. M. (1973). On-line monitoring of eye-position signals in contingent and noncontingent paradigms. *Behavior Research Methods & Instrumentation*, 5(2), 218–228.
- Riggs, K. J., Mather, E., Hyde, G., & Simpson, A. (2015). Parallels between action-object mapping and word-object mapping in young children. *Cognitive Science*.
- Ruggeri, A., Markant, D., Gureckis, T., & Xu, F. (2016). Active control of study leads to improved recognition memory in children. In *Proceedings of the 38th annual conference of the cognitive science society*.
- Russo-Johnson, C., Troseth, G., Duncan, C., & Mesghina, A. (2017). All tapped out:

- Touchscreen interactivity and young children’s word learning. *Frontiers in Psychology*, 8, 578.
- Satterthwaite, T. D., Green, L., Myerson, J., Parker, J., Ramaratnam, M., & Buckner, R. L. (2007). Dissociable but inter-related systems of cognitive control and reward during decision making: evidence from pupillometry and event-related fmri. *Neuroimage*, 37(3), 1017–1031. doi: 10.1016/j.neuroimage.2007.04.066
- Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-prime: User’s guide*. Psychology Software Incorporated.
- Sirois, S., & Jackson, I. R. (2012). Pupil dilation and object permanence in infants. *Infancy*, 17(1), 61–78.
- Smith, L. B., Jayaraman, S., Clerkin, E., & Yu, C. (2018). The developing infant creates a curriculum for statistical learning. *Trends in Cognitive Sciences*.
- Smith, L. B., & Thelen, E. E. (1993). A dynamic systems approach to development: Applications. In *Bradford books series in cognitive psychology*. Cambridge, Massachusetts: The MIT Press.
- Smolak, L., & Weinraub, M. (1983). Maternal speech: strategy or response? *Journal of Child Language*, 10(2), 369–380.
- Swingley, D., Pinto, J. P., & Fernald, A. (1999). Continuous processing in word recognition at 24 months. *Cognition*, 71(2), 73–108. doi: 10.1016/s0010-0277(99)00021-9
- Twomey, K. E., & Westermann, G. (2018). Curiosity-based learning in infants: a neurocomputational approach. *Developmental Science*, 21(4), e12629.
- Von Holzen, K., & Mani, N. (2012). Language nonselective lexical access in bilingual toddlers. *Journal of Experimental Child Psychology*, 113(4), 569–586. doi: 10.1016/j.jecp.2012.08.001
- Wade, S., & Kidd, C. (2019). The role of prior knowledge and curiosity in learning. *Psychonomic bulletin & review*, 1–11.
- Wang, Q., Bolhuis, J., Rothkopf, C. A., Kolling, T., Knopf, M., & Triesch, J. (2012). Infants in control: Rapid anticipation of action outcomes in a gaze-contingent

paradigm. *PLoS ONE*, 7(2), e30884. doi: 10.1371/journal.pone.0030884

Yu, C., & Smith, L. B. (2013). Joint attention without gaze following: Human infants and their parents coordinate visual attention to objects through eye-hand coordination. *PLoS ONE*, 8(11), e79659.

Table 3

LMM testing differences between conditions and age groups.

full <- lmer(PTL_corr ~ ConditionSum + age + z.TestAge + (1 | id) + (1 | Object) + (1 | Name) + (1 | Action), data=m.lmm, REML=F, control = contr)

Group	Factor	Estimates	SE	lower CI	upper CI	LRT	p
Overall	Intercept	0.24	0.05	0.15	0.32	*	*
	ConditionSum	0.05	0.02	0.02	0.09	8.26	< 0.001
	age group	-0.19	0.05	-0.29	-0.10	13.32	< 0.001
	z.TestAge	-0.01	0.03	-0.06	0.04	0.08	0.78
Children	Intercept	0.04	0.03	-0.02	0.11	*	0.2
	ConditionSum	0.04	0.02	0.00	0.09	4.40	0.04
	z.TestAge	0.02	0.02	-0.02	0.06	0.74	0.39
Adults	Intercept	0.23	0.05	0.13	0.35	*	< 0.001
	ConditionSum	0.06	0.03	0.00	0.12	4.11	0.04
	z.TestAge	-0.04	0.06	-0.15	0.07	0.64	0.42

*)Note that coefficients of interactions can only be interpreted in relation to the respective baseline levels of the interacting variables. Further, the significance level of intercepts can only be interpreted in a meaningful way when effects on the intercept are tested. Thus, these values are only displayed when they are informative.

Table 4

LMM evaluating the interaction of preference and target looking in the word-object and action-object condition for in children and adults.

pref.words.children.wordsonly <- lmer(PTL_corr ~ Words_F2 + z.TestAge + Words_S2 + (1 | id) + (1 | Object) + (1 | Name) + (1 | Action), data=subset(m.lmm_children, m.lmm_children\$Condition=="Word"), REML=F, control = contr)

Group	Factor	Estimates	SE	lower CI	upper CI	LRT	p
Children: Words	Intercept	0.09	0.03	0.02	0.15	*	0.005
	Words_F2	-0.00	0.04	-0.07	0.08	0.00	0.99
	z.TestAge	0.03	0.03	-0.03	0.09	0.75	0.39
	Words_S2	-0.03	0.04	-0.09	0.05	0.43	0.51
Adults: Words	Intercept	0.30	0.09	0.12	0.50	*	< 0.001
	Words_F2	0.04	0.06	-0.08	0.16	0.44	0.51
	z.TestAge	-0.10	0.07	-0.22	0.03	1.94	0.16
	Words_S2	0.10	0.07	-0.04	0.23	2.04	0.15
Children: Actions	Intercept	-0.00	0.06	-0.12	0.11	*	0.96
	Actions_F2	-0.02	0.03	-0.10	0.04	0.50	0.48
	z.TestAge	0.01	0.03	-0.05	0.06	0.08	0.78
	Actions_S2	0.04	0.03	-0.03	0.10	1.18	0.28
Adults: Actions	Intercept	0.17	0.05	0.07	0.28	*	0.001
	Actions_F2	0.08	0.05	-0.02	0.18	2.37	0.12
	z.TestAge	-0.01	0.06	-0.11	0.11	0.02	0.88

Continued on next page

Group	Factor	Estimates	SE	lower CI	upper CI	LRT	p
	Actions_S2	0.06	0.05	-0.04	0.17	1.37	0.24

*)Note that coefficients of interactions can only be interpreted in relation to the respective baseline levels of the interacting variables. Further, the significance level of intercepts can only be interpreted in a meaningful way when effects on the intercept are tested. Thus, these values are only displayed when they are informative.

Table 5

GLMM testing differences between conditions and age groups over time including Time, its linear, quadratic, and cubic term.

*pref.action.gca.children <- lmer(PTL_corr.mean ~ (poly1+poly2+poly3)*Actions_F2 + z.TestAge + Actions_S2 + (poly1+poly2 | id) + (poly1+poly2 | Object) + (poly1+poly2 | Name) + (poly1+poly2 | Action), data=subset(m.aggr_children, m.aggr_children\$Condition=="Action"), REML=F, control = contr)*

Group	Factor	Estimates	SE	lower CI	upper CI	LRT	p
Children	Intercept	0.09	0.04	0.001	0.17	*	*
Words	z.TestAge	0.02	0.03	-0.04	0.08	0.33	0.57
	Words_S2	-0.03	0.03	-0.1	0.04	0.59	0.44
	poly1:Words_F2	-0.25	0.16	-0.58	0.08	2.34	0.13
	poly2:Words_F2	-0.05	0.15	-0.33	0.26	0.14	0.71
	poly3:Words_F2	0.1	0.04	0.02	0.19	6	0.01
Adults	Intercept	0.31	0.09	0.12	0.49	*	*
Words	z.TestAge	-0.1	0.07	-0.23	0.03	1.68	0.2
	Words_S2	0.11	0.07	-0.03	0.25	2.36	0.13
	poly1:Words_F2	-0.02	0.08	-0.19	0.14	-0.12	1.00
	poly2:Words_F2	< 0.001	0.08	-0.18	0.15	< 0.001	1.00
	poly3:Words_F2	0.03	0.04	-0.05	0.09	0.43	0.51
Children	Intercept	-0.01	0.06	-0.14	0.11	*	*
Actions	z.TestAge	-0.001	0.02	-0.05	0.04	0.002	0.96
	Actions_S2	0.03	0.03	-0.02	0.09	1.18	0.28
	poly1:Actions_F2	-0.05	0.16	-0.37	0.24	0.11	0.74
	poly2:Actions_F2	0.003	0.12	-0.23	0.22	< 0.001	0.98
	poly3:Actions_F2	0.05	0.04	-0.03	0.13	1.62	0.2
Adults	Intercept	0.18	0.07	0.03	0.32	*	*
Actions	z.TestAge	-0.02	0.05	-0.13	0.09	0.13	0.72
	Actions_F2	0.06	0.05	-0.05	0.18	1.27	0.26
	poly1:Actions_F2	0.12	0.09	-0.04	0.3	1.87	0.17
	poly2:Actions_F2	-0.06	0.1	-0.25	0.13	0.37	0.54
	poly3:Actions_F2	-0.07	0.04	-0.14	-0.01	4.46	0.03

*)Note that coefficients of interactions can only be interpreted in relation to the respective baseline levels of the interacting variables. Further, the significance level of intercepts can only be interpreted in a meaningful way when effects on the intercept are tested. Thus, these values are only displayed when they are informative.