DOI: 10.1111/infa.12464

INFANCY — THE OFFICIAL JOURNAL OF THE INTERNATIONAL CONGRESS OF INFANT STUDIES — WILEY

RESEARCH ARTICLE

When it pays off to take a look: Infants learn to follow an object's motion with their gaze—Especially if it features eyes

Christine Michel[1,2] | **Sabina Pauen**[3] | **Stefanie Hoehl**[4]

[1]Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany

[2]Faculty of Education, Leipzig University, Leipzig, Germany

[3]Institute of Psychology, Heidelberg University, Heidelberg, Germany

[4]Faculty of Psychology, University of Vienna, Vienna, Austria

Correspondence
Christine Michel, Faculty of Education, Leipzig University, Jahnallee 59, 04109 Leipzig, Germany.
Email: christine.michel@uni-leipzig.de

Funding information
Deutsche Forschungsgemeinschaft, Grant/Award Number: HO 4342/2-3; Max-Planck-Gesellschaft

Abstract

Social cues and instrumental learning are two aspects potentially fostering early gaze following. We systematically investigated the influence of social features (schematic eyes vs. reverse-contrast eyes) and gaze-contingent reinforcement (elicited vs. not elicited) on 4-month-olds' learning to attend to gaze-cued objects. In 4 experiments, we tested infants' ($N = 74$) gaze following of a turning block with schematic or reverse-contrast eyes. In Experiments 1 and 2, infants could elicit an attractive animation in a training phase via interactive eye tracking by following the turning of the block. Experiments 3 and 4 were yoked controls without contingent reinforcement. Infants did not spontaneously follow the motion of the block. Four-month-olds always followed the block after training when it featured schematic eyes. When the block featured reverse-contrast eyes, the training phase only affected infants' looking behavior without reinforcement. While speaking to a certain degree of plasticity, findings stress the importance of eyes for guiding infants' attention.

1 | INTRODUCTION

An essential aspect of interpersonal communication is aligning our own attentional focus with that of our interlocutors. Attending to objects in the extension of the gaze direction of others allows us to monitor their focus of attention and to identify external referents of the conversation. Thus, gaze following fundamentally underlies our ability to communicate about the world and to learn from others. It is, therefore, regarded as one of the building blocks of social cognitive and language development (Baldwin, 1995; Brooks & Meltzoff, 2005; Kristen et al., 2011). Here, we address the early ontogeny of gaze following, operationalized as infants' ability to attend to objects in the direction of gaze, and how flexibly it can be generalized to non-human agents through reinforcement learning (see Del Bianco et al., 2019 for a recent review on gaze following).

Even newborns prefer to look at a face with direct gaze compared to a face with gaze averted to the side (Farroni et al., 2002). Further research by Farroni and colleagues revealed that the direction of movement of a central cue plays a more important role for infant gaze cueing than the actual gaze direction of the stimulus face (Farroni et al., 2000). However, the context of an upright face and a period of eye contact preceding the perceived motion of the eyes support gaze cueing in 4-month-olds (Farroni et al., 2003). In another series of studies, it was shown that 4-month-old infants' encoding of peripherally presented target objects is facilitated when these are cued by the gaze and/or head direction of a centrally presented person (Hoehl et al., 2014; Reid & Striano, 2005; Wahl et al., 2013). In these studies, gaze direction and head orientation were equally effective, but a stimulus without eyes (i.e., a car) did not yield the same effect. In the above-mentioned studies, infants were presented with two-dimensional stimuli on a computer screen. Hence, covert attention shifts rather than overt gaze following were tested. When overt gaze following is investigated in more natural live interactions, infants' ability to monitor and follow others' attentional focus appears somewhat more limited. D'Entremont et al. (1997) showed that 3- to 6-month-olds can follow an adult's gaze and head direction when the target of the adult's gaze shift is within the infant's immediate visual field. Between 6 and 18 months of age, infants' ability to correctly identify the target of another person's gaze steadily increases to more distant locations and infants no longer stop at the first object in the scan path when distractor objects are present (Butterworth & Jarrett, 1991; Scaife & Bruner, 1975). However, Corkum and Moore (1998) found little evidence for spontaneous gaze following prior to 10 months and reported that isolated gaze shifts (without head movement) do not seem to elicit gaze following reliably before 18–19 months of age (but see Tomasello et al., 2007, for evidence that 12-month-olds rely more on another person's gaze than head direction when following attention).

The apparent discrepancy between young infants' performance in computer-based studies and older infants' difficulties in more challenging live settings resulted in diverging theories on the ontogenetic origins of gaze following behavior. Offering a rather nativist perspective, Baron–Cohen proposed an innate "eye direction detector" that feeds into a "shared attention mechanism" developing between 9 and 18 months which allows for understanding the intentions of another person based on their gaze direction (Baron-Cohen, 1994). Gliga and Csibra (2007) also stressed newborn infants' special attention to eyes and gaze direction. They proposed that both infants' attention to eye contact as an ostensive signal and their following of referential gaze support the operation of an evolved human-specific social learning system (Csibra & Gergely, 2009).

Focusing on the potential role of learning experiences, Corkum and Moore, in contrast, attributed infants' increasing gaze following behavior across the first two years to instrumental learning starting between 8 and 10 months of age (Corkum & Moore, 1995, 1998). In their view, infants learn to follow other people's gaze direction because they are often rewarded with an interesting sight in the direction of the gaze cue (see also Triesch et al., 2006). To test this hypothesis, Corkum and Moore (1998) conducted training studies rewarding infants with an attractive visual stimulus for either following the adult's gaze direction or for looking in the opposite direction. These studies revealed that 6- to 7-month-olds rarely followed the adult's head and gaze turn to a toy object spontaneously, nor did they learn this response through reinforcement (Corkum & Moore, 1998). Eight- to 9-month-olds showed spontaneous gaze following more often than the younger age group and further increased their gaze following through reinforcement learning. Interestingly, 8- to 9-month-olds did not learn looking in the opposite direction of a person's head and gaze turn equally well. This suggests that although spontaneous gaze following was still quite rare in this age group, previous learning experiences and/ or more basic attention directing mechanisms biased infants' reinforcement learning, thus enabling enhancement of gaze following but not of the opposite behavior.

Further elaborating on the idea that reinforcement learning is crucial for infants' gaze following, Triesch et al. (2006) proposed a computational model integrating several mechanisms and structures, termed a "Basic Set." Reinforcement learning is supposed to support gaze following, as infants discover that their caregiver's gaze will help them to predict interesting sights in the environment. However, complementing this ability to learn through reinforcement, as also proposed by Corkum and Moore (1995, 1998), Triesch and colleagues suggest that infants' early preference for human stimuli as well as basic visual tracking mechanisms, the perception of head pose and gaze direction, habituation (to allow for dynamic shifts of attention) and a structured social environment, that is, caregivers who systematically look at people and relevant objects, will support infants' acquisition of gaze following skills. A range of predictions can be derived from this model. For instance, infants' gaze following should be enhanced when following the direction of a head and/or gaze shift is reinforced, whereas infants should not as easily learn to gaze in the opposite direction. Furthermore, infants should preferentially learn to follow a social cue, due to their early visual preferences for faces, eyes, and biological motion (Farroni et al., 2002; Johnson et al., 1991; Simion et al., 2008).

Building upon this research and modeling work, Michel et al. (2021) tested whether 4-month-old infants' gaze following behavior in a computer-based study would be affected by gaze-contingent feedback. Infants were presented with a central person turning toward one of two cartoon characters (mice) in an interactive eye tracking paradigm. During training, infants were able to elicit an interesting animation of the gaze-cued cartoon character by following the person's head turn toward it. Increased pupil dilation as a measure of arousal in response to the animation indicated the stimulus was interesting to infants. Four-month-olds followed the person's head and gaze shift during baseline and at test (i.e., after training). In line with previous studies, infants thus followed gaze in a relatively simple computer-based task with target objects very close to the centrally presented face. Interestingly, infants who elicited more animations during the training phase showed a greater change in preference to the cued over the uncued cartoon character from baseline to test when following the actor's head and gaze direction. No such pattern was found when the person cued the cartoon character only with her head (keeping the eyes to the front) or only the eyes (keeping the head to the front) or when infants had to look in the opposite direction of the cue during training to elicit the animation. This pattern of results suggests that reinforcement—under certain circumstances—may promote stability of 4-month-olds' gaze following without inducing the opposite behavior, that is, looking in the non-cued direction, in line with the findings of Corkum and Moore (1998) and the predictions from Triesch et al. (2006).

This result raises the question of how flexible young infants' gaze following behavior is. Can infants learn to follow any moving object with their own gaze when being reinforced by an interesting sight in the direction of the cue's movement? Or does infants' preference for human stimuli limit their attention orientation to specific cues (Triesch et al., 2006)? Two previous studies showed that 8-month-old and 12-month-old infants readily follow a faceless (and eyeless) object's rotational movement with their gaze when the object had previously shown contingent "interactive" behavior in response to the infant's looking (Deligianni et al., 2011; Johnson et al., 1998). Objects in these studies also moved in a biological, non-linear manner presumably prompting infants to identify them as animates (Simion et al., 2011). However, 4-month-olds' attention direction does not seem to be affected by a centrally presented nonsocial block's linear rotational movement (Michel et al., 2019). Thus, infants do not indiscriminately follow motion of a large centrally presented stimulus without clear animacy cues.

Infants' already existing gaze following can be influenced by a rewarding experience in line with the direction of a social stimulus (Michel et al., 2021). However, it still remains unclear whether infants' initial start to follow the cue is dependent upon similar characteristics. In this study, we therefore test whether 4-month-old infants follow the direction of the movement of a nonsocial object showing no biological motion. We systematically test the influence of two potential influential factors: the presence of eyes as one of several cues defining a stimulus as a social one (e.g., contingency or biological motion), here manipulated as the presence of eyes versus eye-like patterns with a reversed black-and-white contrast, and the influence of reinforcement (i.e., the gaze-following behavior being reinforced through interesting animations contingent on the infants' gaze behavior vs. no animation and no contingency).

We present infants with a central block featuring black-and-white frontal markings that in Experiments 1 and 3 resemble schematic eyes (black dot on a white background). In Experiments 2 and 4, the contrast of the frontal markings is reversed. Thus, the block is perceptually matched to the block in Experiments 1 and 3, but it does not feature discernible eyes. We chose this manipulation in the design of our stimuli because previous studies have shown that reversing or distorting the characteristic black-on-white contrast of human eyes (Kobayashi & Kohshima, 1997) alters the way stimuli guide infants' attention (Farroni et al., 2005; Michel et al., 2017a,b). During a training phase, infants' following the block's rotational movement to one of two cartoon characters results in an interesting animation of the cued character in Experiments 1 and 2. More specifically, two cartoon mice are shown, one of which starts to wiggle when fixated on. In experiments without contingent reinforcement (Experiments 3 and 4), the cartoon characters never move and, hence, no contingent reaction to the infants' gaze behavior is elicited. By comparing infants' gaze behavior during a baseline and after the training phase (i.e., at test), we are able to test whether reinforcement learning takes place. As the main dependent measure, we analyze the difference score between looking times to the cued and uncued object at baseline and after training (see also Hernik & Broesch, 2019; Senju & Csibra, 2008).

This study allows us to independently vary the presence of social cues and reinforcement to test their independent and combined relevance of young infants' learning of guiding visual attention in a gaze-following paradigm. Four-month-olds are a particularly interesting age group for addressing this question because they show reliable gaze following and attention cueing through gaze cues in computer-based tasks at this age (Astor & Gredebäck, 2019; Hood et al., 1998; Michel et al., 2021) but it is still unclear whether this behavior can be generalized to other objects types through reinforcement learning and to what extend it requires social cues (i.e. eyes).

Previous findings suggest that 4-month-olds are unlikely to show gaze following spontaneously in a nonsocial condition (Michel et al., 2017a; Michel et al., 2019). However, if "gaze following" is fundamentally based on reinforcement learning, infants may learn to follow even a block's rotational movement to a cued target, provided that this behavior is reinforced. A corresponding finding (especially in case of the block with reverse-contrast eyes in Experiment 2) would speak to a high level of flexibility and plasticity in infants' direction of attention.

Alternatively, infants might not perceive a block's motion as directional and thus referring to a peripheral object unless the block features eyes. If infants possess an innate or very early-acquired sensitivity to specifically follow a stimulus featuring eyes (or behavioral cues of an animate agent: Deligianni et al., 2011), they should follow the direction of the block with eyes in Experiment 1 both during baseline and in the test phase after training. However, infants should not follow the block's direction with reverse-contrast eyes in Experiment 2 during baseline and might not even learn to follow this block during the training phase.

A third possibility is that attention cueing specifically through eyes (either based on an innate or based on very early-acquired mechanism) affects infants' looking behavior in conjunction with reinforcement learning (Triesch et al., 2006). In that case, different outcomes seem plausible: (1) Infants may not follow the motion of a block without eyes nor learn following it when being reinforced for this behavior. (2) Infants may not follow any block spontaneously because this stimulus does not resemble a natural face and is highly unfamiliar. However, due to the presence of schematic eyes, infants may learn to follow the motion of this block when this behavior is reinforced, but not the block without eyes. This would speak to a limited degree of flexibility in infants' gaze-following behavior allowing for the generalization of gaze following to stimuli that share some essential social characteristics with human faces, especially eyes.

2 | MATERIAL AND METHODS

Four-month-old infants took part in this (interactive) eye tracking study. To test the influence of natural eyes and contingent reinforcement for the acquisition of gaze following, we systematically varied these two characteristics in a series of 4 experiments (see Table 1 for an overview): In Experiments 1 and 3, infants were presented with a block featuring eye-like markings on the front (see Figure 1). In Experiments 2 and 4, the contrast of these markings was reversed resulting in a white dot on a black background (see Figure 1). Experiments 1 and 2 followed identical procedures. Experiments 3 and 4 were also following this protocol, except that no animation was shown. To control for possible habituation effects to the block itself, the stimulus presentation for each infant in Experiment 3 was matched to one infant's presentation who participated in Experiment 1 (*yoked control*) and the stimulus presentation for each infant in Experiment 4 was matched to one infant's presentation who participated in Experiment 2 *(yoked control)*. That is, in each trial during the training phase, infants watched the block rotate to the side and the end state was shown stationary for as long as the block was present for the matched infant from Experiments 1 or 2, respectively, including the time of the animations in Experiments 1 and 2.

TABLE 1 Overview of the factors varied within the 4 experiments

	Schematic eyes	Reverse-contrast eyes
Contingent reinforcement	Experiment 1	Experiment 2
No contingent reinforcement	Experiment 3	Experiment 4

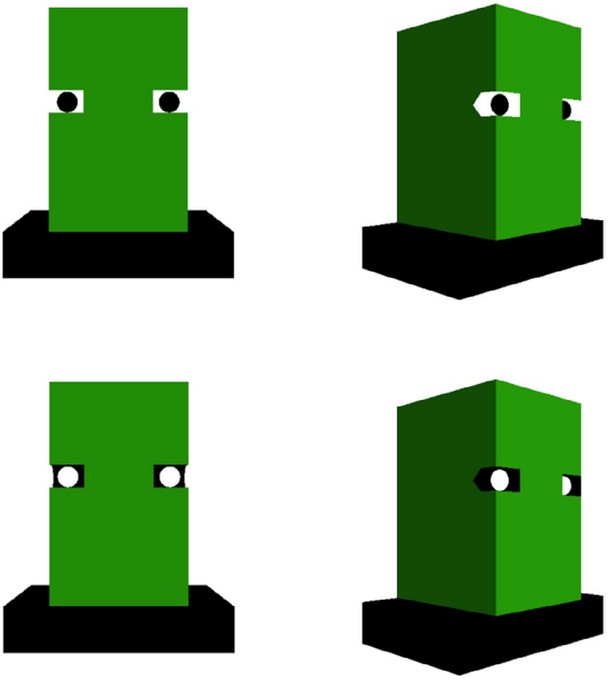

FIGURE 1 Block stimuli used in Experiment 1 and 3 (upper panel) and Experiment 2 and 4 (lower panel)

All experiments were conducted according to guidelines laid down in the Declaration of Helsinki with the understanding and written informed consent of each participant's parent before any data collection. The Ethics Commission from the Medical Faculty of the University of Leipzig approved of the study and all procedures (positive vote received in written form on 03/28/2016).

2.1 | Participants

All participating infants were born full term (>37 weeks) except for one infant in Experiment 4 who was born gestational week 36 and 6 days. They came from predominantly Caucasian families with mainly a middle to high educational and socio-economic background. Experiment 1 and 2 took place at Heidelberg University (Germany), Experiment 3 took place at the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig (Germany) and Experiment 4 took place at University of Vienna (Austria). All studies were recorded with the same technical setup. Based on previous research with similar methods and measures (Michel et al., 2021; Senju & Csibra, 2008), we aimed for a sample size of about $N = 20$ per experiment. This sample size is also sufficient to detect medium effects ($d = 0.6$) given a power of 0.8 which is in line with results of a previous study using the same paradigm (Michel et al., 2021).

In Experiment 1, 21 infants were included in the final sample (12 female), mean age: 4 months, 10 days, age range 4 months 1 day - 4 months 30 days. An additional 4 infants were tested but excluded from the final sample because of our outlier rejection criterion ($n = 2$), because the mother looked at the screen repeatedly during the presentation ($n = 1$) or because of an erroneous calibration

($n = 1$). In Experiment 2, 20 infants were included in the final sample (10 female infants), mean age: 4 months, 14 days, age range 4 months 1 day – 4 months 29 days. An additional 7 infants were tested but excluded from the final sample because of our outlier rejection criterion ($n = 4$), or because they did not provide valid data on at least one trial during baseline or test (i.e., at least 200 ms of looking times to one of the cartoon characters; $n = 3$). In Experiment 3, 17 infants were included (10 female infants), mean age 4 months 14 days, age range 4 months 4 days - 4 months, 23 days. An additional 4 infants were tested but identified as outliers and thus excluded from further analyses.

In Experiment 4, 16 infants were included (9 female infants), mean age 4 months 12 days, age range 3 months 18 days - 4 months, 27 days. An additional 37 infants were tested but excluded from the final sample because they were identified as outliers ($n = 4$), because they did not provide at least one valid trial during baseline and test ($n = 18$), no data were recorded due to technical problems ($n = 2$), or fuzziness of the infant ($n = 4$) or undefined reasons ($n = 3$), or a previously tested infant already provided a good data set for the respective matched timing ($n = 6$). The most plausible reason for this high dropout rate in Experiment 4 is the move of the laboratory to another city with new and relatively inexperienced experimenters performing the data collection.

Replicating the analysis of a study using the same paradigm (Michel et al., 2021) and in line with previous looking time studies in infancy, we excluded infants with relative looking times exceeding 2 SD to the cued or the not cued object in baseline or test (Beier & Spelke, 2012; Cashon et al., 2013), that is, we excluded any infant from further analyses who was an outlier with respect to the other infants on one or more of these four values. In Experiment 3 and 4 (the yoked controls for Experiment 1 and 2), this exclusion of participants lead to the fact that a controlled match did not exist for all participants of Experiment 1 and 2. However, the general pattern of results of Experiment 3 (and 4) was very similar when we did not exclude outliers in Experiment 3 (and 4) and included 21 (or 20) infants each matched to one infant from Experiment 1 (Experiment 2). We also excluded infants who did not provide data for at least one trial during the baseline or the test phase (Michel et al., 2021).

2.2 | Stimuli

In Experiment 1, a green block on a black pedestal was presented in the middle of the screen on a white background (see Figure 1). The block featured two markings on its front resembling schematic eyes (black sphere on a white background). The 3D-animations of the block were created using the software Blender v2.67 (Blender Development Team, 2013)). On the left and right side of the block, a small cartoon mouse (the same on both sides) was shown at a size of 6.7 cm × 6.7 cm (visual angle of 6.4° × 6.4°), each presented at a distance of 3.8 cm to the block. The mouse is not displayed here due to copyright restrictions. The block presented in frontal view covered 13.5° × 12.0° of the screen. Turned 45° to the side, it covered 13.2° × 15.1° of the screen. Each cartoon character was 6.4° high and 6.4° wide.

In Experiment 2, the same block was presented, but the contrast of the eye-like markings on the front was reversed resulting in a white sphere on a black background, thus no longer resembling schematic eyes.

Experiments 3 and 4 served as a yoked control condition for Experiments 1 and 2, respectively. Therefore, each infant in this experiment saw the exact same stimulus presentation as one of the infants in Experiments 1 or 2 without being able to control the presentation through contingent feedback and without the animation of the mouse.

2.3 | Procedure

Infants were tested in a quiet and dimly lit room. They were seated on their parent's lap, 60 cm away from the presentation screen. The parent was instructed not to talk or otherwise interact with the infant and to look at the back of the infant's head during the stimulus presentation.

The experiment consisted of a baseline phase, a training phase and a test phase (see Figure 2). Each trial in each phase started with a black star on a white background (5.6 cm × 6.0 cm, visual angle of 5.3° × 5.7°) that served as a central attention attractor. As soon as the infant looked toward the screen, the experimenter initiated the trial by button-press. The baseline consisted of 4 trials. In each trial, the central block and the two cartoon characters on the side were shown for 1 s. Then, the block was shown rotated to the right or left side (2 trials each, randomized order) facing one of the two cartoon characters. To create an effect of apparent motion, we subsequently showed a picture of the frontal block and the laterally shifted block. This lateral frame was held for 5 s.

The training phase consisted of 8 trials. The starting image was the same as in the baseline trials. Then, the block was rotated to the right or left side (4 trials each, randomized order). This frame was held for up to 10 s. If the infant looked within the predefined area of interest (AOI) encompassing the cued mouse during this phase, an animation was elicited: the cartoon character started wiggling for 2 s before the next trial was started. More specifically, the mouse's upper body and head slightly swung from side to side while the lower body swung in the opposite direction, creating the impression of the mouse performing a dance. Thus, when infants elicited the animation by looking at the cued mouse, the training trial lasted until the infant looked at the correct AOI, plus 2 s of animation. In case that the infant failed to look at

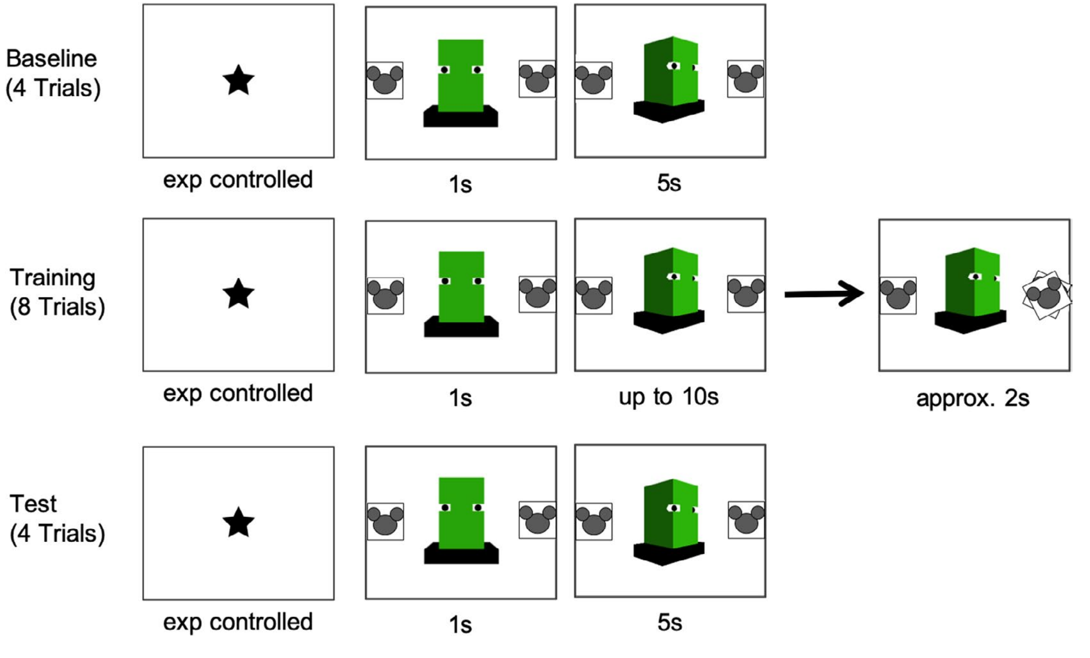

FIGURE 2 Illustration of the paradigm of Experiment 1. Each infant completed a baseline phase, a training and a test phase. Animations of the cued cartoon characters (displayed here in a schematic way because of copyright restrictions), could only be elicited during training trials in Experiment 1 and 2 and lasted for 2 s

the correct AOI, no animation was elicited and the next trial started automatically after 10 s. Infants elicited 4–8 animations (average 6.95) in Experiment 1 and 5–8 animations (average 7.2) in Experiment 2. In Experiment 3 and 4, no animation was presented and timing was matched to the stimulus presentation of one of the infants previously tested in Experiment 1 and 2, respectively.

The test phase consisted of 4 trials and was identical to the baseline phase. Thus, as in the baseline phase, no animation could be elicited by following the cue's movement to one of the cartoon characters.

2.4 | Eye tracking recording and analyses

Stimuli were presented on a Tobii T60 eye tracking monitor using the Psychophysics Toolbox version 3.12.05 (Brainard & Spat, 1997; Kleiner et al., 2007), a toolbox for Matlab (The Mathworks, Natick, USA), for the stimulus presentation and the Matlab-based Talk2Tobii version. 1.1.0 software created by Luca Filipin, Fani Deligianni and Andrew T. Duchowski (http://psy.ck.sissa.it/t2t/About_T2T.html) for the online evaluation of gaze data. A 5-point infant calibration procedure was applied. As a successful calibration is crucial for interactive eye tracking, we validated the calibration afterwards. Therefore, we presented pink spirals (5.3 cm × 5.3 cm, visual angle of 5.1° × 5.1°) on the left and on the right side of the screen after the calibration. The experimenter visually checked whether infants' gaze points were located on novel stimuli and not systemically shifted. If an error was observed, we calibrated the infant again or excluded the infant from the analysis. We compared looking times to the cued and uncued cartoon characters during baseline and test. The respective rectangle AOIs were defined covering each cartoon character, identical to the AOIs that were used to provide gaze-contingent feedback during training (1° of visual angle larger than the mice). Visual preference for the cued or uncued was analyzed using relative looking times (cumulative gaze samples within the AOI relative to the overall gaze samples to the screen).

Each infant contributed 3 to 4 trials for the baseline in Experiment 1 (mean: 3.9) and 1 to 4 trials in the test phase (mean: 3.6). In Experiment 2, each infant contributed 3 to 4 trials in the baseline (mean: 3.9) and 2 to 4 trials in the test phase (mean: 3.6). In Experiment 3, each infant contributed 3 to 4 trials in the baseline (mean: 3.9) and 3 to 4 trials in the test phase (mean: 3.8). In Experiment 4, each infant contributed 2 to 4 trials in the baseline (mean: 3.8) and 2 to 4 trials in the test phase (mean: 3.1).

3 | RESULTS

Previous studies mostly examined gaze following by analyzing infants' first gaze shift to a (looked-at) target or infants' looking time to a target. In our study, we focused on the latter and used a difference score (DS) between relative looking times to the cued and uncued object as the dependent variable to investigate whether infants' gaze was influenced by the direction of the central cue (Hernik & Broesch, 2019; Michel et al., 2021; Senju & Csibra, 2008). Thus, a positive score indicates a looking preference for the cued mouse, whereas a negative score indicates a preference for the uncued mouse. Means and standard errors for this measure are depicted in Figure 3. The means of fixation times toward cued and uncued objects and standard deviations can be found in Table 2. We focused on the duration of infants' looking

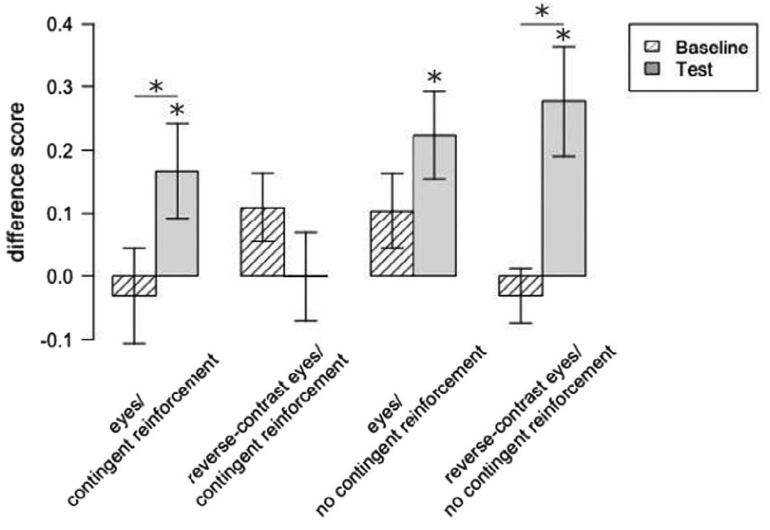

FIGURE 3 Difference scores of relative looking times to the cued and uncued objects for each experiment. Mean values are depicted for baseline and test. Error bars indicate standard errors. *$p < .05$ (statistical comparisons between baseline and test or against 0, i.e. chance level)

toward the objects, because we were interested in whether infants' overt attention could be reliably shifted toward one of two peripheral targets by an inanimate stimulus featuring eyes versus reverse-contrast eyes in baseline or test. We also include additional analyses on first gaze shift from the block to one of the objects which is also often used in research on infant gaze following, but which may be less reliable because it is based on only one measurement point per trial and may thus be more susceptible to unsystematic variances. In addition, we assumed that it may be more difficult for infants to detect the direction of our unfamiliar artificial stimulus at first sight as compared to the typical face stimuli used in previous studies. We, therefore, wanted to give infants the full 5s of presentation time to explore the stimuli and base our analyses on the averaged response of infants during the cueing phase and less on their initial responses.

3.1 | Overall ANOVA across experiments

We predicted that infants' looking behavior would vary from baseline to test depending on the experimental treatment they received (i.e., schematic vs. reversed-contrast eyes, contingent reinforcement vs. no contingent reinforcement). To test for significant differences between experiments depending on phase (baseline vs. test), we ran a repeated-measures ANOVA with the within-subjects factor phase (baseline vs. test) and the between-subjects factors eyes (schematic vs. reverse-contrast) and contingency (yes vs. no). The difference score between relative looking times to the cued and uncued object was used as dependent variable. We found a significant phase x eyes x contingency interaction, $F_{(1,70)} = 8.85$, $p = .004$, partial $\eta^2 = 0.112$. Too resolve this significant interaction, we ran separate *t*-tests contrasting difference scores for baseline versus test for each of the four experiments. All *t*-tests were performed two-tailed with a significance level of 0.05.

TABLE 2 Mean (standard deviation) of the relative looking times to the cued and uncued mouse during the baseline and the test phase for each of the 4 experiments

	Exp. 1: schematic eyes/ contingent reinforcement		Exp. 2: reverse-contrast eyes/ contingent reinforcement		Exp. 3: schematic eyes/no contingent reinforcement		Exp. 4: reverse-contrast eyes/ no contingent reinforcement	
	Baseline	**Test**	**Baseline**	**Test**	**Baseline**	**Test**	**Baseline**	**Test**
Cued	0.33 (0.11)	0.37 (0.11)	0.38 (0.10)	0.34 (0.13)	0.35 (0.09)	0.37 (0.11)	0.33 (0.09)	0.39 (0.11)
Uncued	0.37 (0.15)	0.30 (0.17)	0.31 (0.10)	0.34 (0.13)	0.29 (0.11)	0.24 (0.12)	0.35 (0.06)	0.24 (0.13)

3.2 | Experiment 1: Schematic eyes and contingent reinforcement

The difference score during test was significantly greater than the difference score during baseline, $t_{(20)} = -2.4$, $p = .028$, $d = -0.52$. The difference score in the baseline phase had a mean of −0.03 (standard error: 0.07) indicating no clear preference for either cued or uncued objects, $t_{(20)} = -0.4$, $p = .68$, $d = -0.08$, when tested against 0. The difference score in the test phase had a mean of 0.17 (standard error: 0.07), indicating a significant preference for the cued over the uncued object when tested against 0, $t_{(20)} = 2.2$, $p = .038$, $d = 0.48$.

3.3 | Experiment 2: Reverse-contrast eyes and contingent reinforcement

No significant effects were found, all $ps > .05$. The difference score in the baseline phase had a mean of 0.1 (standard error: 0.05); the difference score at test had a mean of −0.001 (standard error: 0.07).

3.4 | Experiment 3: Schematic eyes without contingent reinforcement

The difference score during test was not significantly greater than the difference score during baseline, $t_{(16)} = -1.31$, $p = .210$, $d = 0.32$. The difference score in the baseline phase had a mean of −0.10 (standard error: 0.06) indicating no clear preference for either cued or uncued objects, $t_{(16)} = 1.7$, $p = .10$, $d = 0.41$, when tested against 0. However, the difference score in the test phase had a mean of 0.22 (standard error: 0.07), indicating a significant preference for the cued over the uncued object when tested against 0, $t_{(16)} = 3.23$, $p = .005$, $d = 0.78$.

3.5 | Experiment 4: Reverse-contrast eyes without contingent reinforcement

In Experiment 4, the difference score during test was significantly greater than the difference score during baseline, $t_{(15)} = -4.01$, $p = .001$, $d = 1.00$. The difference score in the baseline phase had a mean of −0.03 (standard error: 0.04) indicating no clear preference for either cued or uncued objects, $t_{(15)} = -0.73$, $p > .25$, $d = 0.18$, when tested against 0. However, the difference score in the test phase had a mean of 0.28 (standard error: 0.09), indicating a significant preference for the cued over the uncued object when tested against 0, $t_{(15)} = 3.18$, $p = .006$, $d = 0.80$.

3.6 | Additional analysis: First gaze shift

An additional analysis determined whether infants' first gaze shifts from the block to one of the targets following the rotational movement of the block tended to land on the cued or the uncued mouse above chance level. We ran a repeated-measures ANOVA with the within-subjects factor phase (baseline vs. test) and the between-subjects factor eyes (schematic vs. reverse-contrast) and contingency (yes vs. no). As the dependent variable, we calculated a difference score separately for the baseline and the test phase by subtracting the number of trials with first gaze shift to the uncued mouse from the number of trials with a first gaze shift to the cued mouse and dividing the result by the total number of trials with a first gaze shift (Senju & Csibra, 2008). We did not find any significant main effects or interactions, all $ps > .05$.

4 | DISCUSSION

In this interactive eye tracking study, we systematically tested whether 4-month-old infants acquire the ability to follow a schematic gaze, that is to attend to objects in the cued direction, and whether this acquisition is dependent on social features such as eyes and reinforcement learning applied through a gaze-contingent animation. Our results suggest an interaction of both factors. As expected, infants did not spontaneously attend to the direction of the block to a peripheral target, revealing no baseline preference in any of the 4 experiments. However, in the experiments with schematic eyes (Experiment 1 and 3), infants started to attend to the cued direction over the course of the experiment, regardless of whether they received reinforcement or not for this and they also revealed a significant preference for the cued target at test.

For the experiments with reversed-contrast eyes, the pattern of findings looks different: In Experiment 2, even though infants reliably elicited the animation during training, infants did not reveal any significant change in their looking pattern, but in Experiment 4, (without contingent reinforcement) infants did start to attend to the direction of the block and showed a significant preference for the cued target at test.

How can this surprising pattern of findings (i.e., infants starting to follow the block with reverse-contrast eyes only in the absence but not in the presence of reinforcement) be explained? First, comparing Experiment 1 and 2, infants at the age of 4 months may register reinforcement for (gaze) following only in combination with social cues, for instance cues featuring eyes. When reinforcement is paired with a nonsocial stimulus, it may even be rather confusing for infants and therefore may not lead to learning. Alternatively, reinforcement may work best when it is coupled not only with social but also with familiar stimuli. In real life, infants are more familiar with black dots on white backgrounds (i.e. black pupils on white sclera) than with white dots on black backgrounds. At first sight, our block must have been unfamiliar to infants as they have never seen it before. However, it may be that it was easier for infants to familiarize themselves with the block with schematic eyes over the course of the experiment. Thus, in our study, we cannot disentangle whether it is the social aspect or the familiarity aspect of the schematic eyes which fosters the impact of reinforcement in Experiment 1 versus Experiment 2. Another explanation refers to the possibility that the animations of the cartoon characters during the training phase distracted infants from the central block and the change in its orientation in Experiment 2, whereas the cartoon characters never moved, thus leaving attentional resources for the block and its orientation in Experiment 4.

A post-hoc analysis is in line with this explanation (see Supplementary Analysis): Infants decreased their looking times to the block and increased their looking times to mice during the training phase in experiments which contained contingent reinforcement (Experiment 1 and 2) as compared to the experiments without contingent reinforcement (Experiment 3 and 4). Thus, whenever an animation could be elicited, infants spent more time looking at the (moving) mice as compared to the yoked control conditions without animations. Spending more time looking at the block during the training phase in Experiment 4 as compared to Experiment 2, infants may have been more familiarized to the unfamiliar block by the test phase, thus being able to take its orientation into account. Keeping this in mind, we cannot be sure whether our results only reflect the influence of reinforcement due to contingency, although an enhanced pupil size in a previous study using the same animation hints on this explanation (Michel et al., 2021). Additionally, the contingent responses of the mice may have attracted infants' attention to the mice, therefore presumably increasing infants' interest in the mice in Experiment 1 and 2.

It is important to note that the dropout rate of participants in Experiment 4 is much higher than the dropout rate of participants in the other experiments. However, as stated in the Methods section, this is very likely due to the fact that the laboratory moved to another city and Experiment 4 was the first study using our equipment in the new laboratory including relatively unexperienced experimenters. We do not think that the high number of excluded infants in Experiment 4 relate to the results in any systematic way, as the main dropouts came from collecting not enough valid data (e.g., due to the experimenter taking too long to set up the study) but experimenters did not influence infants' gaze behavior during the experiment, which could have let to changes in the results.

In contrast to the reverse-contrast cue in Experiment 2 and 4, infants were able to quickly learn to attend to the block's direction within 8 training trials, resulting in a solid looking preference for the cued over the uncued target at test in Experiments 1 and 3. This learning effect did not rely primarily on the reinforcement of infants' "gaze" following behavior as we found a similar, though slightly weaker, effect in Experiment 3 where infants only saw the motion of the block without being able to elicit an animation. Although—as mentioned before—infants' attention was caught more by the wiggling of the mice in Experiment 1 and 2, the naturally appearing eyes in Experiment 1 may have enabled infants to associate the reinforcement to the stimulus and therefore made them attend to the direction of the block with eyes at test (see Supplementary Analysis).

Based on theoretical accounts stressing the importance of reinforcement learning for infants' gaze following development (Corkum & Moore, 1998), we would have predicted that infants learn to follow both blocks based on reinforcement learning during the training phase, thus displaying a visual preference for cued targets at test in Experiments 1 and 2. This was not the case, as infants exclusively learned to attend to the direction of the block with schematic eyes when this behavior was contingently reinforced. As both blocks were perceptually matched, this finding supports the idea of a special status of eye-like stimuli for young infants' attention direction. As we tested 4-month-old infants, however, we are not able to tell whether this advantage of eye-like stimuli relies on an evolved neural mechanism that does not require learning at all or whether 4 months of visual experience with faces and eyes affected infants' sensitivity to eyes in our study.

Theories positing evolved neural mechanisms dedicated to directing infants' attention to eyes (e.g., Baron-Cohen, 1994) would have predicted that infants follow the "gaze" direction of a centrally presented stimulus featuring eyes right away. This claim is not supported by our data. Infants did not initially attend to the direction of the block with eyes during baseline phase of Experiment 1. In contrast, it seems that it took some learning experiences for infants to follow the block's direction with their own gaze. Perhaps neural mechanisms dedicated to processing eyes did not immediately respond to our highly unfamiliar block stimulus. However, infants activated their "gaze" following behavior in response to this stimulus very quickly despite it showing linear, non-biological motion unlike stimuli presented in previous studies on gaze following in response to "interactive," but faceless stimuli in older infants (Deligianni et al., 2011; Johnson et al., 1998). This effect was more pronounced in Experiment 1, where we applied interactive eye tracking and reinforced infants' "gaze" following, compared to Experiment 3, where infants were simply exposed to the block turning to the cartoon characters. However, even in Experiment 3, we observed some evidence for gaze following at test, that is infants showing a preference for the cued mouse. Thus, simply observing the turning motion of the block toward one of two cartoon characters sufficed for infants to, after a while, perceive the motion as directional and attend to this direction it with their own gaze. We suggest that our findings speak to both a specific (acquired or evolved) sensitivity of young infants for eyes as well as a certain degree of plasticity and flexibility allowing for generalization of gaze following to specific unfamiliar objects as long as they feature eyes. We did not find clear evidence that reinforcement alone plays a generalized role for infants' acquisition of gaze following behavior in our set of experiments. When paired with a more social stimulus (here, the stimulus with eyes in Experiment 1) reinforcement enhanced infants' tendency to attend to cued objects in contrast to Experiment 3 (without reinforcement). However, without the social stimulus (i.e., in Experiment 2 and 4 with eyes with reversed contrast), reinforcement did not facilitate infants' increase in their attentional preference. This is in line with the results by Michel et al. (2021) using the same paradigm. In their study, the authors reported a weak effect on infants' already existing gaze following only when reinforcement was paired with a simultaneous movement of head and gaze to the side, but not in their other conditions (the actor moving only the head or only the gaze to the side). In contrast, in this study, we used an even more artificial cue (a green box with schematic eyes) and infants did not show spontaneous gaze following in baseline. Taken together, both studies suggest that reinforcement may foster gaze following or at least change infants' way to attend to cued objects, but only if it is coupled with a social stimulus.

To exploit the richness of eye tracking data, we included an additional analysis which was not initially planned on infants' first gaze shift from the block to one of the two objects. This analysis revealed no significant influence of social stimulus (schematic eyes vs. reverse-contrast eyes) or contingency on infants' first look. This discrepancy between the looking times and the first look data could be due to the fact that first gaze shift may be influenced by a range of factors (e.g., large movements, unsystematic factors causing an initial bias to one side) and therefore essentially measure something else than the accumulated looking times to one of two targets over the duration of the trial, i.e. a more sustained overt shift of attention. In addition, first gaze shifts are only based on one measurement point per trial, while looking times take the time-frame of the entire trial into account. As we tested relatively young infants and exposed them to artificial unfamiliar central cues, it may have taken them longer to extract the direction of the central stimuli leading to initial gaze shifts which are relatively unrelated to the central cue at first but—as the results show—to a more directed looking behavior over the course of the 5s of the trial.

Some limitations of this study should be mentioned. To not overstrain infants' attention span within one experimental session, we performed only 8 training trials. Our results show that this was sufficient for infants to learn to attend to the direction of a previously unfamiliar stimulus, but not in all conditions. Whether more or longer learning opportunities lead to different results needs to be examined by future studies. At this point, we can only conclude that given identical learning opportunities, infants more readily learn to align their gaze with the motion of a stimulus featuring eyes compared to a very similar stimulus featuring no eyes when experiencing reinforcement for this behavior. As a consequence, the number of trials available for analyses was limited. Although infants contributed $M = 3.1$ to $M = 3.9$ trials (out of 4) per phase, some infants contributed less data and one infant only contributed one single trial to the test phase of Experiment 1. This may have influenced our findings in terms of underestimating the effects of reinforcement. To fully evaluate the impact of contingency learning on infants' gaze following, future studies may consider to prolong the training phase.

It should also be noted that we performed the test phase immediately following the training phase. This implies that we cannot draw any conclusion on possible long-term learning effects. It is also not possible to make any claims about the generalization of the observed training effects above and beyond the stimuli we presented, as we used identical stimuli at baseline, training and test. More research is clearly needed to clarify whether infants' gaze following behavior generalizes to similar looking or even completely different stimuli with similar eye-like markings. It is worth mentioning that we cannot know for sure whether infants actually perceived the stimuli in Experiment 1 and 3 as eyes and as no eyes in Experiment 2 and 4, respectively. However, the stimuli were designed in congruence with previous studies showing that reversing or distorting the black-on-white contrast of eye-like stimuli alters the effect of eye-like stimuli in guiding infants' attention (Farroni et al., 2005; Michel et al., 2017a,b).

The advantages of an experimental computer-based study are the highly controlled stimuli enabling us to manipulate details like the contrast of the eyes. On the downside, this experimental control diminishes the ecological validity of the study. In daily life, gaze following takes place in naturalistic contexts and interactions and previous literature has shown that other characteristics of the situation like the identity of the interlocutor (Gredebäck et al., 2010) or hand movements (Yu & Smith, 2013, 2017) play a role for infants' attention going beyond gaze direction. Finally, eye tracking technology sets limits to the age groups that can be tested. Although it would be highly interesting to test newborns in order to minimize the effects of prior learning experiences, this would not be feasible with the setup and technology we used in the current experiments.

To conclude, our results demonstrate that 4-month-old infants can be induced to attend to the direction of an object's linear rotational movement with their gaze. However, 4-month-olds in our study did not indiscriminately learn to follow any object motion. They only quickly learned to follow the direction of a block featuring eyes, even in the absence of reinforcement, while learning to follow a block's direction with reverse-contrast eyes only without reinforcement. This suggests a certain degree of flexibility of infants' gaze following behavior when shaped through learning while at the same time speaking to a special sensitivity of 4-month-old infants to the presence of eyes.

ACKNOWLEDGEMENTS

This research was supported by the Max Planck Society and by a grant by the Deutsche Forschungsgemeinschaft (DFG) [Grant Number HO 4342/2-3] awarded to Stefanie Hoehl and Sabina Pauen. The authors declare no conflicts of interest with regard to the funding source for this study. We are grateful to the infants and parents who participated. The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Christine Michel https://orcid.org/0000-0001-6150-4825
Sabina Pauen https://orcid.org/0000-0001-5129-9004
Stefanie Hoehl https://orcid.org/0000-0003-0472-0374

REFERENCES

Astor, K., & Gredebäck, G. (2019). Gaze following in 4.5- and 6-month-old infants: The impact of proximity on standard gaze following performance tests. *Infancy*, *24*(1), 79–89. https://doi.org/10.1111/infa.12261

Baldwin, D. A. (1995). Understanding the link between joint attention and language. *Joint attention: Its origins and role in development*.

Baron-Cohen, S. (1994). How to build a baby that can read minds: Cognitive mechanisms in mindreading. *Cahiers De Psychologie Cognitive/Current Psychology of Cognition*, *13*(5), 513–552.

Beier, J. S., & Spelke, E. S. (2012). Infants' developing understanding of social gaze. *Child Development*, *83*(2), 486–496. https://doi.org/10.1111/j.1467-8624.2011.01702.x

Blender Development Team. (2013). Blender (Version 2.67) [Computer software]. https://www.blender.org

Brainard, D. H., & Spat, V. (1997). The psychophysics toolbox. *Spatial Vision*, *10*(4), 433–436. https://doi.org/10.1163/156856897X00357

Brooks, R., & Meltzoff, A. N. (2005). The development of gaze following and its relation to language. *Developmental Science*, *8*(6), 535–543. https://doi.org/10.1111/j.1467-7687.2005.00445.x

Butterworth, G., & Jarrett, N. (1991). What minds have in common is space: Spatial mechanisms serving joint visual attention in infancy. *British Journal of Developmental Psychology*, *9*(1), 55–72. https://doi.org/10.1111/j.2044-835X.1991.tb00862.x

Cashon, C. H., Ha, O. R., Allen, C. L., & Barna, A. C. (2013). A U-shaped relation between sitting ability and upright face processing in infants. *Child Development*, *84*(3), 802–809. https://doi.org/10.1111/cdev.12024

Corkum, V., & Moore, C. (1995). Development of joint visual attention in infants. In C. Moore, & P. Dunham (Eds.), *Joint attention: Its origins and role in development* (pp. 61–83).

Corkum, V., & Moore, C. (1998). The origins of joint visual attention in infants. *Developmental Psychology*, *34*(1), 28–38. https://doi.org/10.1037/0012-1649.34.1.28

Csibra, G., & Gergely, G. (2009). Natural pedagogy. *Trends in Cognitive Sciences*, *13*(4), 148–153. https://doi.org/10.1016/j.tics.2009.01.005

D'Entremont, B., Hains, S. M. J., & Muir, D. W. (1997). A demonstration of gaze following in 3- to 6-month-olds. *Infant Behavior & Development*, *20*(4), 569–572. https://doi.org/10.1016/s0163-6383(97)90048-5

Del Bianco, T., Falck-Ytter, T., Thorup, E., & Gredebäck, G. (2019). The developmental origins of gaze-following in human infants. *Infancy*, *24*(3), 433–454. https://doi.org/10.1111/infa.12276

Deligianni, F., Senju, A., Gergely, G., & Csibra, G. (2011). Automated gaze-contingent objects elicit orientation following in 8-months-old infants. *Developmental Psychology*, *47*(6), 1499–1503. https://doi.org/10.1037/a0025659

Farroni, T., Csibra, G., Simion, F., & Johnson, M. H. (2002). Eye contact detection in humans from birth. *Proceedings of the National Academy of Sciences of the United States of America*, *99*(14), 9602–9605. https://doi.org/10.1073/pnas.152159999

Farroni, T., Johnson, M. H., Brockbank, M., & Simion, F. (2000). Infants' use of gaze direction to cue attention: The importance of perceived motion. *Visual Cognition*, *7*(6), 705–718. https://doi.org/10.1080/13506280050144399

Farroni, T., Johnson, M. H., Menon, E., Zulian, L., Faraguna, D., & Csibra, G. (2005). Newborns' preference for face-relevant stimuli: Effects of contrast polarity. *Proceedings of the National Academy of Sciences of the United States of America*, *102*(47), 17245–17250. https://doi.org/10.1073/pnas.0502205102

Farroni, T., Mansfield, E. M., Lai, C., & Johnson, M. H. (2003). Infants perceiving and acting on the eyes: Tests of an evolutionary hypothesis. *Journal of Experimental Child Psychology*, *85*(3), 199. https://doi.org/10.1016/s0022-0965(03)00022-5

Gliga, T., & Csibra, G. (2007). Seeing the face through the eyes: A developmental perspective on face expertise. In C. von Hofsten, & K. Rosander (Eds.), *Progress in brain research* (Vol. *164*, pp. 323–339). Elsevier.

Gredebäck, G., Fikke, L., & Melinder, A. (2010). The development of joint visual attention: A longitudinal study of gaze following during interactions with mothers and strangers. *Developmental Science*, *13*(6), 839–848. https://doi.org/10.1111/j.1467-7687.2009.00945.x

Hernik, M., & Broesch, T. (2019). Infant gaze following depends on communicative signals: An eye-tracking study of 5- to 7-month-olds in Vanuatu. *Developmental Science*, *22*(4), e12779. https://doi.org/10.1111/desc.12779

Hoehl, S., Wahl, S., & Pauen, S. (2014). Disentangling the effects of an adult model's eye gaze and head orientation on young infants' processing of a previously attended object. *Infancy*, *19*(1), 53–64. https://doi.org/10.1111/infa.12035

Hood, B. M., Willen, J. D., & Driver, J. (1998). Adult's eyes trigger shifts of visual attention in human infants. *Psychological Science*, *9*(2), 131–134. https://doi.org/10.1111/1467-9280.00024

Johnson, M. H., Dziurawiec, S., Ellis, H., & Morton, J. (1991). Newborns' preferential tracking of face-like stimuli and its subsequent decline. *Cognition*, *40*(1–2), 1–19. https://doi.org/10.1016/0010-0277(91)90045-6

Johnson, S. C., Slaughter, V., & Carey, S. (1998). Whose gaze will infants follow? The elicitation of gaze-following in 12-month-olds. *Developmental Science*, *1*(2), 233–238. https://doi.org/10.1111/1467-7687.00036

Kleiner, M., Brainard, D., Pelli, D., Ingling, A., Murray, R., & Broussard, C. (2007). What's new in psychtoolbox-3. *Perception*, *36*(14), 1–16.

Kobayashi, H., & Kohshima, S. (1997). Unique morphology of the human eye. *Nature*, *387*(6635), 767–768. https://doi.org/10.1038/42842

Kristen, S., Sodian, B., Thoermer, C., & Perst, H. (2011). Infants' joint attention skills predict toddlers' emerging mental state language. *Developmental Psychology*, *47*(5), 1207–1219. https://doi.org/10.1037/a0024808

Michel, C., Kayhan, E., Pauen, S., & Hoehl, S. (2021). Effects of reinforcement learning on gaze following of gaze and head direction in early infancy: An interactive eye-tracking study. *Child Development*, *92*(4). https://doi.org/10.1111/cdev.13497

Michel, C., Pauen, S., & Hoehl, S. (2017a). Schematic eye-gaze cues influence infants' object encoding dependent on their contrast polarity. *Scientific Reports*, *7*(1), 7347. https://doi.org/10.1038/s41598-017-07445-9

Michel, C., Wronski, C., Pauen, S., Daum, M. M., & Hoehl, S. (2019). Infants' object processing is guided specifically by social cues. *Neuropsychologia*, *126*, 54–61. https://doi.org/10.1016/j.neuropsychologia.2017.05.022

Michel, C., Wronski, C., Pauen, S., Daum, M. M., & Hoehl, S. (2017b). Infants' object processing is guided specifically by social cues. *Neuropsychologia*, 1873–3514. https://doi.org/10.1016/j.neuropsychologia.2017.05.022

Reid, V. M., & Striano, T. (2005). Adult gaze influences infant attention and object processing: Implications for cognitive neuroscience. *European Journal of Neuroscience*, *21*(6), 1763–1766. https://doi.org/10.1111/j.1460-9568.2005.03986.x

Scaife, M., & Bruner, J. S. (1975). The capacity for joint visual attention in the infant. *Nature*, *253*(5489), 265–266. https://doi.org/10.1038/253265a0

Senju, A., & Csibra, G. (2008). Gaze following in human infants depends on communicative signals. *Current Biology*, *18*(9), 668–671. https://doi.org/10.1016/j.cub.2008.03.059

Simion, F., Di Giorgio, E., Leo, I., & Bardi, L. (2011). The processing of social stimuli in early infancy: From faces to biological motion perception. *Progress in Brain Research*, *189*, 173–193. https://doi.org/10.1016/b978-0-444-53884-0.00024-5

Simion, F., Regolin, L., & Bulf, H. (2008). A predisposition for biological motion in the newborn baby. *Proceedings of the National Academy of Sciences*, *105*(2), 809–813. https://doi.org/10.1073/pnas.0707021105

Tomasello, M., Hare, B., Lehmann, H., & Call, J. (2007). Reliance on head versus eyes in the gaze following of great apes and human infants: The cooperative eye hypothesis. *Journal of Human Evolution*, *52*(3), 314–320. https://doi.org/10.1016/j.jhevol.2006.10.001

Triesch, J., Teuscher, C., Deák, G. O., & Carlson, E. (2006). Gaze following: Why (not) learn it? *Developmental Science*, *9*(2), 125–147. https://doi.org/10.1111/j.1467-7687.2006.00470.x

Wahl, S., Michel, C., Pauen, S., & Hoehl, S. (2013). Head and eye movements affect object processing in 4-month-old infants more than an artificial orientation cue. *British Journal of Developmental Psychology*, *31*(2), 212–230. https://doi.org/10.1111/bjdp.12001

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. https://doi.org/10.1371/journal.pone.0079659

Yu, C., & Smith, L. B. (2017). Hand-eye coordination predicts joint attention. *Child Development*, *88*(6), 2060–2078. https://doi.org/10.1111/cdev.12730

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: Michel, C., Pauen, S., & Hoehl, S. (2022). When it pays off to take a look: Infants learn to follow an object's motion with their gaze—Especially if it features eyes. *Infancy*, *00*, 1–18. https://doi.org/10.1111/infa.12464