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SHORT COMMUNICATION
Adult gaze influences infant attention and object processing: implications for cognitive neuroscience

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Abstract

Infants follow others' gaze toward external objects from early in ontogeny, but whether they use others' gaze in processing information about objects remains unknown. In Experiment 1, 4-month-old infants viewed a video presentation of an adult gazing toward one of two objects. When presented with the same objects alone a second time, infants looked reliably less at the object to which the adult had directly gazed (cued object). This suggests that the uncued object was perceived as more novel than the object previously cued by the adult's gaze. In Experiment 2, adult gaze was not directed towards any object. In this control experiment, infants looked at both objects equally in the test phase. These findings show that adult eye gaze biases infant visual attention and information processing. Implications of the paradigm for cognitive neuroscience are presented and the results are discussed in terms of neural structures and change over ontogeny.

Introduction

Humans show a robust sensitivity to other's eyes. Already from birth infants look longer at someone with direct compared to averted gaze (Farroni *et al*., 2004). By 3–4 months of age, infants reliably follow the direction of an adult's eye gaze (D'Entremont *et al*., 1997; Hood *et al*., 1998), and manifest enhanced neural processing of faces with direct compared to averted gaze (Farroni *et al*., 2002). The ability to tune into and follow other's eye gaze is considered foundational to several aspects of social and cognitive development (Woodward, 2003; Striano & Stahl, in press). However, despite the significance of this ability in developing a wide range of social-cognitive skills, the function of early gaze following has not been investigated.

The majority of studies to date have questioned the significance of infants' gaze following, for instance asking whether this skill can be explained by associative learning mechanisms (see Moore & Corkum, 1995) or by an awareness of others' intentions (see Carpenter *et al*., 1998; also, Johnson *et al*., 1998). In the current study, we used the working hypothesis that infants do follow gaze, at least by 4 months of age, and we asked how this inclination might influence infants' processing of objects. In other words, regardless of the underlying processes that evoke the early gaze following mechanism, we asked whether following an adult's gaze toward an object subsequently influences processing of the object. By investigating infants at 4 months of age, the present study will enlighten research on the use of overt or covert attention and suggest development of cortical structures associated with the operations inherent in processing these stimuli.

Interestingly, previous research has investigated infant processing of eye gaze (Hood *et al*., 1998; Farroni *et al*., 2002) and of object processing (de Haan & Nelson, 1999); however, the relationship between eye gaze and object processing has never been investigated. In the current study, we addressed this open question using a behavioural novelty preference paradigm. Infants watched an adult gaze at one of two objects and then were later presented with both objects again. We predicted that if infants use adult's eye gaze to direct attention to a spatial location, then during a second presentation of the two objects, they would show a novelty preference for the uncued object (that is, they would look longer at an object that was not cued by the adults' gaze) irrespective of the location of the object. Finally, in order to confirm the infants' gaze following in Experiment 1, a second experiment was conducted in which the eyes of the adult did not move from their original depiction of a forward stare. If the infants used adult gaze to facilitate attention to a location in Experiment 1, then in Experiment 2 we predicted no preference for either object, as the adult's direction of gaze would not bias infant attention.

Materials and methods

Experiment 1

Participants

The final sample consisted of 22 4-month-old infants (age range from 15–17 weeks; median, 16 weeks). Thirteen males and nine females participated in the experiment. An additional six infants were tested but not included in the final sample due to inattentiveness or fussiness ($n = 5$), or a technical error ($n = 1$). All infants were born full-term

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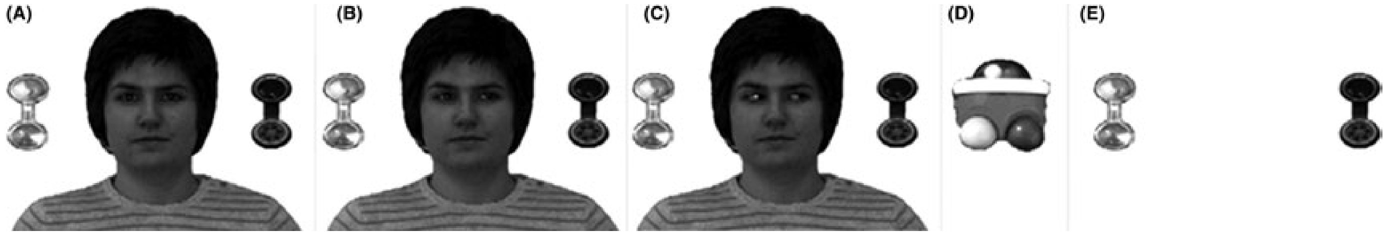

FIG. 1. Schematic of stimuli. (A) Direct gaze; (B) eye movement (C) final gaze; (D) central attractor and (E) presentation of two objects.

(37–42 weeks gestation), were of normal birthweight (> 2500 g) and were recruited in Germany. Written consent was obtained prior to testing.

Stimuli

Stimuli were presented on a video screen with stimuli delivered via a projector. Each trial began with a central image of a human face, gazing towards the camera with direct gaze. Example stimuli are shown in Fig. 1. As can be seen on the figure, one object was positioned on either side of the face. Each object was placed the same distance from the periphery of the face. The objects were presented at the same time as the face appeared on screen. After a one-second central fixation, the eyes proceeded to slowly gaze towards one object (eye movement, 0.5 s). The final gaze was held for one second. In order that attention was not biased to one location during the second phase of the stimuli presentation, an attractor depicting an image of a bright yellow toy was presented centrally for 2 s in order to attract infant gaze to the centre of the display. Following this, a paired preference test phase began in which two objects were presented for 10 s and infant looking time towards the two objects was measured. The objects were either in the same locations as during the initial presentation, or were reversed in location. This assessed infant patterns of looking to previously cued and uncued objects. Two faces were used for each condition, yielding four stimuli presentations in total (objects in same location, objects in reversed location × two faces). These were presented in a random order to infants and were integrated with four other stimuli not related to this study.

Data analysis

Prior to testing, infant's looking to each location (left, central or right) was filmed. During the presentation of stimuli, the video output was split into four separate quadrants with video feed from three cameras. One quadrant captured the stimuli; one focused on the infant's upper face and eyes as viewed from the front; the third quadrant depicted the infant's head in profile and the fourth was left clear. The locations left, central and right were each separated by a visual angle of 24.8° when viewed from a distance of 120 centimetres. The direction of infant looking in the ten-second paired preference test phase were compared to the frames of looking to each location that were obtained prior to testing. As eye-tracking software was not used in this study, we estimate errors during coding of up to 7° of the visual angle. This margin of error successfully excludes the possibility that infants were looking in any location other than the direction of the location of one particular object or of the centrally presented face.

Looking times in the direction of the location of the objects were coded in seconds using on-line coding software (Interact, Mangold) by a research assistant who was naïve to the objectives of the study. Inter-rater reliability measures were obtained offline for five infants, with Pearson correlations yielding scores of (R) 0.97 for the cued location and 0.94 for the uncued location.

Experiment 2

Participants

The final sample consisted of 19 4-month-old infants (age range from 14.5 to 18 weeks, median, 16 weeks). Nine males and ten females participated in the experiment. An additional five infants were tested but not included in the final sample due to inattentiveness ($n = 1$) or fussiness ($n = 4$). All infants were born full-term (37–42 weeks gestation), were of normal birthweight (> 2500 g) and were recruited in Germany.

Stimuli

The stimuli were exactly the same as those in Experiment 1, with the modification that the adult's eyes did not move from their initial forward gazing position. Thus the stimuli in Experiment 2 were the same as those depicted in Fig. 1, with the exception that the eyes did not move from their initial position and consequently remained as illustrated in Fig. 1A.

Data analysis

Assessment was made of looking time in seconds in the direction of each individual object. It should be recalled that as the adult did not gaze towards any object, there was no eye gaze (or cue) to analyse in this experiment. As there were four objects used, six paired samples *t*-tests were conducted that compared infant looking time in the direction of each object with every other object. There were thus *t*-tests comparing objects 1 and 2; 1 and 3; 1 and 4; 2 and 3; 2 and 4; 3 and 4.

Inter-rater reliability measures were obtained offline for four infants, with Pearson correlations yielding scores from (R) 0.99–0.98 for those objects in the left location and from 1.0 to 0.92 for those objects in the right location.

Results

Experiment 1

A 2 × 2 repeated measures ANOVA was performed on infants' gazing with Cue (cued, uncued) and Location (changed, unchanged) as within-subjects variables. Results showed that infants looked reliably longer at uncued compared to cued objects ($F_{1,21} = 5.659$, $P = 0.027$); see Fig. 2. There was no significant effect of location or interaction between cue and location, suggesting that changing the location of the objects had no effect on what infants perceived as more novel. When the same

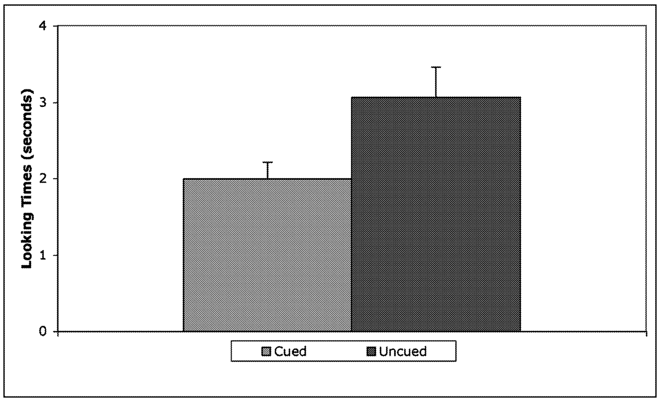

FIG. 2. Looking times towards the location of objects cued by adult gaze or uncued by adult gaze, demonstrating increased looking towards the uncued relative to cued objects.

ANOVA was conducted with the addition of gender as a between-subjects factor, no between-subjects effect was found ($P > 0.05$).

Experiment 2

Paired sample *t*-tests were conducted, with looking times in the direction of each object compared to looking times towards the other objects. There were no significant differences in looking time towards any object relevant to any other object ($P > 0.05$ in all cases), suggesting that all objects were processed equally and that no object was perceived as more novel than any other object. The result of this control experiment confirms that infants in Experiment 1 were biased to process specific objects due to the direction of adult gaze.

Discussion

Infants reliably follow gaze by 3–4 months of age, but the function of this capability has not been investigated. In Experiment 1, we used a novelty paradigm to assess whether an adult's gaze influenced infant's processing of a cued object. The results showed that there was indeed bias in object processing created by the gaze of the adult.

This effect is most likely due to enhanced processing of the cued object during the initial gaze phase. That is, the uncued object may have been more novel as it has been looked at less than the cued object during the initial presentation of the objects with the face and gaze component. The fact that a previous adult gaze to one object influenced infant looking behaviour to the objects during the subsequent object presentation suggests that others' gaze influences 4-month-old infants' processing of objects.

By 4 months of age, infants use the direction of gaze of an adult to facilitate attention to a location. This in turn biases processing of information from that location relative to objects in other locations. Objects in uncued locations are therefore inherently more novel than objects that appeared in cued spatial locations. These findings fit well with other evidence of gaze following in early infancy (Hood *et al*., 1998; Farroni *et al*., 2002; Reid *et al*., 2005). These data also show that infants' attention is not simply tethered; rather the object at which they look is processed, with information about the object extracted. The information obtained may include (for example) the shape or colour of the object.

Interestingly, in Experiment 1, the adult only gazed directly toward the cued object for one second and the eyes moved for only 0.5 s. Therefore, infants detected the change in eye orientation quickly. They also rapidly processed some salient aspect of the object that was cued, for there was only 2.5 s of total time available for viewing the display that included the face and two objects. Our results suggest that much of that time was spent engaged with the action of the face, as the gaze of the face clearly biased the processing of information from this display. This conclusion is further reinforced by the results of Experiment 2, where the adult's eyes did not gaze at any object location. In that experiment, infants did not increase looking to any particular object, suggesting that all objects were processed equally.

It is possible that cortical neural pathways mediated the overt behaviour that was measured in Experiment 1. As Pack & Born (2001) note, the visual world is exceedingly complex and studies into the parameters of the human visual system have only uncovered the most basic of concepts. Perhaps the most complex visual information humans experience is the flow of motion that is human movement. Of these movements, eye gaze is perhaps the most important for an infant to process and interpret. This is because infants may use the direction of an adults' gaze to determine what is salient in the environment. This enhanced attention might allow infants to predict what objects the adult will act upon, thereby providing time for the infant to react socially and emotionally to changes that occur in the setting following the adult's action. This interpretation relies upon conscious allocation of attention to a location in a visual scene, thereby suggesting the functional use of cortical rather than subcortical structures by infants, consistent with prior models of neural visual development (e.g. Atkinson, 2000). However, future studies are needed to test such an interpretation.

These data suggest that already by 4 months of age, infants use adult eye gaze as a simple 'orientation of attention' device. It is possible that this rudimentary orientation mechanism is a required precursor to the establishment of more robust joint attention skills by the end of the first year. In order to make such conclusions, it must first be established whether nonsocial attractors may also influence infants' processing of objects in the same fashion as eye gaze. If this is found to be the case, then this paradigm can be altered to answer key questions on the ontogeny of joint attention. In other fields of cognitive neuroscience, this paradigm could address the neural basis of information extraction from a complex visual scene in a more realistic manner than is currently utilized in many laboratories.

This paradigm is capable of adaptation to allow further studies in the cognitive neurosciences on the topics of attention, visual information processing and neurodevelopment. As the scope for such research is broad, the use of this paradigm in these fields is encouraged. Of particular importance for the field of developmental cognitive neuroscience is the need to establish the relationship between behavioural changes in infancy related to information processing and the neural mechanisms involved in such processes. The paradigm allows further exploration into the neural correlates to attention, specifically those aspects of visual attention mediated by social cognition – with eye gaze biasing information to specific spatial locations. This new paradigm has the potential to inform many issues in the cognitive sciences.

Conclusion

In summary, here we demonstrate that adult eye gaze biases infant attention. The perception of objects that have been previously gazed towards by adults are not considered as inherently interesting by infants as objects that have not been gazed towards. This result suggests overt attentional shifts and therefore the use of cortical structures. One goal of future research should be to test a wider age range of infants and to determine the selectivity of this response as a function of development. While infants follow others' gaze from the early months, the function of this skill was unclear. Here we show that this ability allows information processing between an infant and another person. Such a capability allows infants to predict the actions of others, which is foundational to understanding intentions and goal directed behaviours.

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