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Individual differences in object-processing explain the relationship between early gaze-following and later language development

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A B S T R A C T

Gaze-following behaviors play an important role in language development. However, the way in which gaze-following contributes to language development remains unclear. By focusing on two abilities, namely following the gaze direction of others and processing a cued object, the present study investigated how these two influences work together to promote language development in a longitudinal approach on infants from 9 to 18 months of age. The results demonstrated that infants who spent more time following the gaze direction toward an object were more efficient in processing the cued object at 9 months and had larger vocabularies by 18 months. Mediation analyses showed that the relationship between early gaze-following behavior and subsequent vocabulary size was explained by object-processing ability. Importantly, mere extended fixations on a target object without the initiation of another's gaze shift were not related to enhanced object-processing. Our findings suggest that following another's gaze shift toward the object has an impact on object-processing that could contribute to vocabulary development, elucidating a critical step in the path from early gaze-following ability to later language development.

1. Introduction

The observation of others' behavior enables infants to acquire new information about their surroundings. Joint attention, especially gaze-following which is defined as looking toward the object of another person's attention, allows infants to engage in social interactions with others, and this behavior is typically established between 6 and 12 months of age (Tomasello, 1995; Tomasello, Carpenter, Call, Behne, & Moll, 2005). During parent–child interactions, parents often label the objects at which they are looking. In this situation, infants who follow the gazes of others are in a better position for word learning because they use an adult's gaze as a good clue to the referent of the adult's label. In fact, several studies have identified a relationship between gaze-following and language acquisition (e.g., Baldwin, 1995; Baldwin & Moses, 2001; Bruner, 1983; Mundy & Gomes, 1998; Slaughter & McConnell, 2003; Tomasello, 2003). Toddlers' vocabulary is predicted by the frequency of mothers' and infants' joint visual attention (Tomasello & Todd, 1983). In addition, a longitudinal study revealed a strong positive correlation between gaze-following behavior at 10–11 months and subsequent vocabulary scores at 18 months (Brooks & Meltzoff, 2005) or at 2 years (Brooks & Meltzoff, 2008, 2015). These findings indicate that following the gaze direction of others plays an important role in early language development.

However, the way in which gaze-following contributes to language development remains unclear. Recently, some researchers have argued that gaze-following behaviors consist of two abilities: following the gaze direction and processing a cued object (Okumura, Kanakogi, Kanda, Ishiguro, & Itakura, 2013a, 2013b; Reid & Striano, 2005; Theuring, Gredebäck, & Hauf, 2007). For example, Okumura, Kanakogi, Kanda, Ishiguro, and Itakura (2013a) investigated whether following another's gaze toward an object subsequently influenced the processing of the object. In their study, 12-month-olds were presented with videos in which a female human or a robot model looked at one of two objects. In the subsequent object-processing test, the two objects (i.e., the (cued) target and alternative (uncued) object) were shown, and the manner in which the infants processed the object

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information was assessed by measuring the time spent looking at the objects. The result demonstrated that although 12-month-olds followed the gaze direction of both a human and a robot, they looked reliably longer at the uncued object than at the cued object when it had been previously gazed at by the human but not by the robot in the object-processing test; this novelty preference for uncued objects indicates that infants process a previously cued object as more familiar than an uncued object as a result of the effects of the human's gaze shift, and that the uncued object was more interesting than the cued object (e.g., Cleveland, Schug, & Striano, 2007; Cleveland & Striano, 2007; Hunter & Ames, 1988; Reid & Striano, 2005; Theuring et al., 2007). Thus, these findings suggest that the infants' object-processing was enhanced as a function of human gaze direction, whereas the infants did not use robot gaze to enhance object-processing. When we consider the findings showing that infants attribute communicative and referential intention to human agents but not to robot or nonhuman agents (Boyer, Pan, & Bertenthal, 2011; Okumura, Kanakogi, Kanda, Ishiguro, & Itakura, 2013c), enhanced object-processing reflects the comprehension of referential intent from others' gaze. Taken together, these findings indicate that gaze-following behaviors can be divided into just following the gaze direction and processing the target object based on the comprehension of referential gaze.

By focusing on the two abilities, namely following the gaze direction and processing the cued object, the present study investigated how these two abilities work together to promote language development. Word learning involves an understanding of the referential nature of the link between spoken words and an object (Baldwin, 1993, 1995). That is, for word learning, infants have to actively discern the speaker's referential gaze direction and to identify the cued object. Actually, it has been shown that infants cannot learn new words by using a robot's gaze direction because they do not attribute a referential nature to a robot's gaze (O'Connell, Poulin-Dubois, Demke, & Guay, 2009). Therefore, to scrutinize the mechanism of the relationship between gaze-following and language development, it is insufficient to consider only following behavior. The ability both to follow the gaze direction and to process the cued object based on comprehension of the referential gaze appears to be crucial for word learning.

Specifically, if infants understand the referential gaze, they will follow the gaze direction of others toward an object and after that, process the cued object, as suggested by Okumura et al. (2013a). Therefore, among gaze-following, object-processing efficiency, and language development, we hypothesize that following the gaze direction precedes processing the cued object in a temporal sequence, and such sequential behaviors might contribute to language development. Since we assume a sequential pathway between gaze-following and object-processing, our research posed the following questions: Is the ability to follow another's gaze linked to the ability to process a cued object, and if so, do individual differences in object-processing ability mediate the well-established relationship between early gaze-following and later vocabulary size? To answer these questions, we used mediation analysis, which reveals the understanding of the developmental pathways linking early gaze-following, object-processing, and vocabulary size. We hypothesized that the well-established relationship between early gaze-following and subsequent vocabulary size is mediated by object-processing ability. When the infants were 9 months old, we assessed their ability to follow the gaze direction of others toward an object and to process the cued object information using the procedure described by Okumura et al. (2013a). When the infants were 18 months old, we analyzed their vocabulary size using the MacArthur-Bates Communicative Development Inventory (CDI).

2. Experiment 1

2.1. Methods

2.1.1. Participants

Informed consent was obtained from the parents prior to the participants' involvement in the study. The participants were 37 9-month-old infants (18 boys, 19 girls; mean age: 274.2 days; range: 262–287 days). All the infants were growing up in a monolingual environment where they learned Japanese as their native language and were recruited from the Kyoto area. Seven additional infants were tested but excluded from the analyses because of calibration errors (n = 1), a failure to meet the inclusion criteria by completing fewer than 3 trials of gazing at one of the objects in the following phase (n = 3), or for failing to retrieve the MacArthur CDI form (n = 3).

2.1.2. Apparatus

A Tobii T60 Eye Tracker (Tobii Technology) recorded the infants' looking behaviors. An integrated 17-inch TFT monitor presented the video stimuli. Each infant was seated on a parent's lap with the infant's eyes approximately 60 cm from the monitor. A five-point calibration was conducted prior to eye-movement recording.

2.1.3. Stimuli and procedure

Our procedure was identical as that employed by Okumura et al. (2013a). In the following phase, the infants viewed six video clips (subtending $25.8^\circ \times 19.4^\circ$ of the visual angle) in which a female model gazed at one of two objects ($7.6^\circ \times 6.7^\circ$) (left, Fig. 1a–c). Each video began with a scene in which the model looked down at the table (2 s). Next, the model looked up (1 s) and then fixated straight ahead (2 s). After that the model turned her head and eyes toward (1 s) and fixated on (5 s) one of the two objects. The model's gaze was always directed toward the same object, but the object's location was changed in an ABBABA order (i.e., A = left and B = right or vice versa). The object at which the model gazed and the initial direction of the model's gaze (to left or right) were counterbalanced across the participants. The model maintained a neutral facial expression and remained silent throughout the entire sequence.

In the object-processing test phase, a video showing the two objects on a black background was presented for 30 s (Fig. 1d). Although other studies (e.g., Cleveland & Striano, 2007; Theuring et al., 2007) used a 10-s response period, we chose the 30 s employed by Okumura et al. (2013a) because longer periods can assess individual differences by measuring sustained attention. The presentation location (left or right) of the two objects was counterbalanced across the participants. Therefore, half of the infants were shown the test video in which the objects appeared in the same location as the last trial of the following phase, and the other half were shown the test video in which the object appeared at the switched location.

2.1.4. Data analysis

In the following phase, the infants needed to gaze at one of the two objects in at least three out of six trials to be included in the final analysis. We defined the experimenter's target as the cued object and the other object as the uncued object.

As a measurement of gaze-following, we calculated the infants' *first looking* for each trial, which was designated as 'correct looks' (+1) if the first eye-movement from the model's face went to the cued object, 'incorrect looks' (−1) if it went to the uncued object, or 'nonlooks' (0) if the infants did not look at either object. As a standard in gaze-following literature, the first looking score for