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Publication Date

Peer reviewed

The contingency symmetry bias as a foundation of word learning: Evidence from 8-mont-olds in a matching-to-sample task

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Abstract

The contingency symmetry inference, the inference to generalize a learned contingency to a reverse direction, is known to be extremely difficult for non-human animal species (Lionello-DeNolf, 2009). In contrast, humans are known to have the "affirming the consequent fallacy", which reverses the antecedent and the consequence (if P then Q: Q therefore P). The contingency symmetry bias has been long discussed in relation to the ontogenesis of language learning, as word learning requires understanding of bidirectional relationship between symbols and objects. But how this bias emerges has not been known. This research tested whether 8-month-old human infants have this bias on a matching-to-sample task. The results demonstrated the possession of this bias in human infants before they start active word learning. This bias is likely a uniquely human cognitive bias, which may explain why only humans have language.

Keywords: thinking bias; language learning; word learning; ontogenesis of language; animal cognition; heuristic thinking

Introduction

Language is founded on the symmetrical relationship between symbols and referents, and understanding this bi-directional relationship is critical for word learning. Suppose that a mother picked up an apple and said to her boy, "Look, this is an apple; it is called 'apple'." If the boy seemed to remember the sound [ǽpl] and can say the word at that time, the mother naturally expects that at a different time, her son will be able to pick out the red, round object called "apple" when she asks him to get her an apple from a bowl containing various kinds of fruit. When he hands the apple to her, the mother would not think that her boy made an inference, a kind that most non-human animals cannot make to respond to her request.

A plethora of previous studies have shown that the inference human children make so naturally is not at all naturally made by non-human animals (D'amato et al., 1985). In one study, chimpanzees were trained to match a symbol when given a color. They had learned to select the proper symbol for each color, as trained. During the test, the order of the contingency was switched: the symbol was presented first and the chimpanzees were to choose the color they had learned to match (Tomonaga et al., 1991; Yamamoto & Asano, 1995). Surprisingly, as soon as the directionality of the contingency was reversed, the chimpanzees began responding randomly (also see Dugdale & Lowe, 2000). This inability/unwillingness to generalize the learned/known contingency in the reverse direction is in fact shared by almost all non-human animal species, including pigeons, monkeys, baboons (see Lionello-DeNolf, 2009; Völter & Call, 2017 and Yamazaki, Ogawa & Iriki, 2008, for review). Some researchers have trained animals on the contingencies in both directions (symbol→object and object→symbol) extensively and tested whether the animals would be able to generalize the learned contingency in the reverse direction for a new stimulus set (e.g., Kojima, 1984). Even with this bi-directional training, these animals did not spontaneously accept the reversed contingency with a new stimulus set (Horne & Lowe, 1996).

In contrast to the robust unwillingness to reverse the learned contingency in non-human animal species, humans are known to have the "affirming the consequent fallacy" (e.g., Damer, 2001; Hastie & Dawes, 2001), which reverses the antecedent and the consequence (if P then Q: Q therefore P). This is often observed in various types of reasoning in everyday contexts, especially in the fallacy of confusing a necessary condition with a sufficient one (Hastie & Dawes, 2001).

The repeated failure to demonstrate the presence of the contingency symmetry bias in non-human animals on one hand and the strong bias to accept the reversed contingency in humans on the other hand, the origin of this bias (the contingency symmetry bias hereafter) is very important for understanding the origin of language. One possible scenario for why humans possess the contingency symmetry bias is *because* they continuously experience the reversal of contingency relations in language learning, whereby they must map from a symbol to a referent and from a referent to a symbol simultaneously (Tomonaga et al., 1991; cf. Oaksford, 2008). To examine this hypothesis, Dugdale and Lowe (2000) tested three chimpanzees who had received language training for over 10 years. The chimpanzees were trained to learn associations between colors and symbols in one direction (color→symbol); they were then tested whether they would generalize the contingency in the other direction (symbol→color). It turned out that these chimpanzees did not generalize the learned contingency to the reversed direction. The literature thus suggests that non-human animals, regardless of whether they have had experience in extensive language training, are not likely to generalize learned contingencies in the reversed order, which further suggests that mere experience of bi-directional association between symbols and objects does not lead to the emergence of the contingency symmetry bias.

The literature suggests that the contingency symmetry bias is deeply rooted in human thinking, from heuristic causal attributions in everyday situations to hypothesis construction and evaluation by scientists (Oaksford, 2008). In contrast to the strong inclination to make abductive inferences in humans, it is not commonly observed in non-human animals. In a field study, Cheney and Seyfarth (1990, reviewed in Völter & Call, 2017) presented wild vervet monkeys with snake tracks on the ground to test whether these animals would detect danger of pythons being nearby from the tracks. Although the monkeys understood that the tracks were made by their predators, they did not make alarm calls, which indicates that vervet monkeys are not likely to make the backward (causal) inference when witnessing a python trail.

A body of research across different animal species has suggested that the ability to make such backward reasoning is at best limited in non-human animals (see Völter & Call, 2017 for an extensive review; particularly see Table 3 for a summary of the literature). Thus, researchers in comparative psychology have long considered the possibility that the contingency symmetry bias may be what critically divides the mode of thinking between humans and non-human animal species. Given that this bias is necessary for learning of word meanings (Dugdale & Lowe, 2000; Horne & Lowe, 1996; Tomonaga et al., 1991; Yamamoto & Asano, 1995), a critical question for the ontogenesis of language, is whether this bias present in human infants prior to word learning, or it is acquired through the experience of word learning.

A recently published cross-species study (Imai et al., 2021) addressed this question by comparing 8-month-old human infants, who are still mostly engaged in learning the phonological properties (Stager & Werker, 1997), and adult chimpanzees. In this study, the habituation switch paradigm, a widely used method for testing infants' learning of word-referent associations, was used for both species. Both human infants and chimpanzees were trained on two temporal contingencies that did not involve words. Human infants and chimpanzees were familiarized with two pairs of object-movement sequences, in which each object was always followed by one of the two movements. In the critical test (i.e., the symmetry test), the temporal order of the contingency was reversed. In half of the test trials, the pairings between the object and the movement/sound were retained; in the other half, the pairings were switched. If the participants possess the contingency symmetry bias, even if the event started from the consequence of the trained contingency (i.e., starting from the movement), they should expect that the pairing between the object and the movement they had witnessed during the familiarization would be retained.

The results provided evidence for the possession of the contingency symmetry bias in pre-linguistic (semantic) human infants, but not in chimpanzees: The 8-month-old infants looked at the target object longer when the learned contingency was switched, even when the temporal order of the contingency was reversed; In contrast, although chimpanzees showed evidence to have learned the object-movement association during the training phase, at the symmetry test, they did not show discrimination between the familiarized and novel pairings. Based on these results, Imai et al. (2021) suggested that this cognitive bias may be one of the key reasons why only humans have language.

However, Imai et al. (2021) examined the contingency symmetry bias with a temporal contingency, asking whether participants would generalize the learned contingency to a reversed temporal order. This type of the symmetry bias is relevant to backward reasoning, which plays a critical role in causal reasoning (A usually happens after B. B is observed. Hence it is likely that A had happened). However, word learning is founded on a bidirectional association between a symbol and an object. In fact, in the literature of animal cognition, the contingency symmetry bias has been most commonly tested using the matching-to-sample (MTS) paradigm. For example, chimpanzees are shown a set of color blocks and trained to match each block to the corresponding symbol (e.g., a green block→○ and a yellow block→△). At the symmetry test, ○ is shown with an array of different color blocks to see if the chimpanzees would choose the green block from an array.

Thus, to establish that the symmetry contingency bias is a prerequisite of language learning and it is available before human infants begin active learning of word meanings, it is important to examine the presence of this bias in prelinguistic human infants on the MTS paradigm. In this research, we tested whether 8–10-month-old human infants possess the contingency symmetry bias using a method which assimilates the MTS paradigm testing non-human animals in comparative psychology.

Infants were trained to associate two pairs of objects (A1→B1 and A2→B2), with a reward of movement and sound emission of the paired object (Figure 1). Object A1 fell from the top-center of the monitor and disappeared behind the screen. Two objects, B1 and B2, were visible throughout the trial. When A1 went behind the screen and became invisible, one object (B1) moves with a sound, which served as a reward. At the symmetry test, the order of the contingency was reversed such that B1 fell and hid behind the screen. If the infants possess the contingency symmetry bias, they should look at the target object (the one that was paired at the familiarization phase), but not at the distractor object, prior to and/or at the timing when B1 (or B2) went behind the screen and A1 (or A2) began to move with the sound during the familiarization phase.
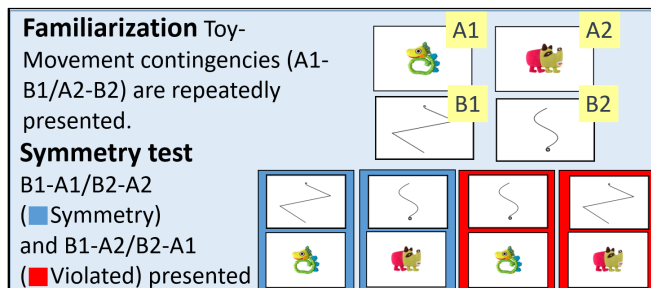

Figure 1: The structure of the temporal contingencies in Imai et al. (2021).

Experiment

Method

Participants
Thirty-one 8-month-old infants (mean age = 8 months 29 days, range = 8 months 1 day-9 month 27 days, STD=0.74 MO, 17 boys) participated in the study. An additional 11 infants were excluded from data analysis due to fussiness, failure to habituate, or mechanical error. All caretakers of infants gave written informed consent before participating in the study. This study was approved by the Ethics Committee of Tamagawa University.

Data recording
The infants' looking behavior was recorded during the familiarization phase and the test phase using a Tobii TX300 eye-tracker (Tobii Technology AB, Tokyo, Tobii Japan). The size of the monitor was 1280 x 960 pixels. Sampling rate of

the data was 120 Hz. The monitor was evenly divided to 6 ROIs: upper left, upper center, upper left, bottom left, bottom center, bottom right. The target object (see below) was located either at the bottom left or bottom right ROI (Figure 2 for the size of the monitor and each ROI).

Stimuli and design
Familiarization phase. Infants were familiarized with two pairs of associations (A1→B1 and A2→B2) (Figure 3). For example, Object A1 went down with a sound (Object falling segment, 6.5 sec) and hid behind the screen. Object B1 (target) and Object B2 (distractor) were located at the bottom and visible throughout the trail. The sound accompanying the sample object (e.g., Object A1) lasted for another 2 seconds after it hid behind the screen to indicate that the object was still there behind the screen (the falling object hidden segment). Object B1 then started to move with a novel sound for 3.5 seconds, while Object B2 stayed still (the reward segment). In a different trial, Object A2 fell down and hid behind the screen, and Object B2 moved with a sound. The sound was the same for B1 and B2 so that it would not be a cue.
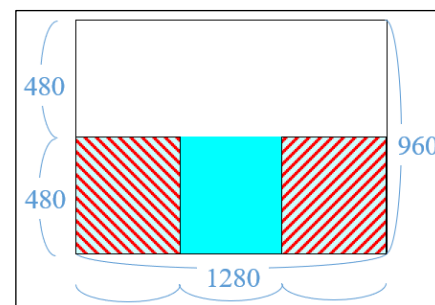

Figure 2: The size of each ROI. The target object was shown in the striped regions.

During the familiarization phase, each block consisted of 4 trials of the same falling object. The location of the target object was counterbalanced: it appeared twice at the left and twice at the right in a random order. To proceed to the test phase, within a block of four trials (see above) with the given falling object (e.g., A1), the infant needed to look at the target object (B1) at the first look before the reward started for 200 milli seconds or longer. When s/he passed this criterion for both A1 and A2, the familiarization phase was ended by the program and the first test (the same-direction association test) began.

The same-direction association test. The test phase consisted of two parts. In the first part, the establishment of the two associations was checked in the same direction as in the familiarization phase (A→B), but no reward (the movement and sound emission of the target object) was given here. Infants' looking to the target object was measured through the trial. When the infant passed the same direction test (see below), s/he moved to the second test phase—the symmetry test. As in the familiarization phase, each block consisted of

4 trials with the same falling object. The two blocks (one with A1 and the other with A2) were alternated with the order counterbalanced.

To proceed to the symmetry test phase, the infant needed to clear the same two criteria for passing the familiarization phase on the same-direction association test. Remember that this test was identical to the familiarization phase with an exception that the target object (B1 or B2) did not move or emit sound. This means that the infants had to show evidence for having learned the associations for both event types (A1 →B1 and A2→B2), with and without the reward.

Symmetry test. At the symmetry test, Object B1 (or B2) was shown at the top and Objects A1 and A2 were placed at the bottom of the monitor. Object B1 (or B2) fell down and hid behind the screen. The target object (the one which was paired during the learning phase) did not move. If the infants possess the contingency symmetry bias, they would look at the target object in anticipation to see the reward before or at the timing the reward started during the familiarization phase. The symmetry test included only 4 trials: two trials with B1 (with the target (A1) appearing at the right and left position each) and two trials with B2.
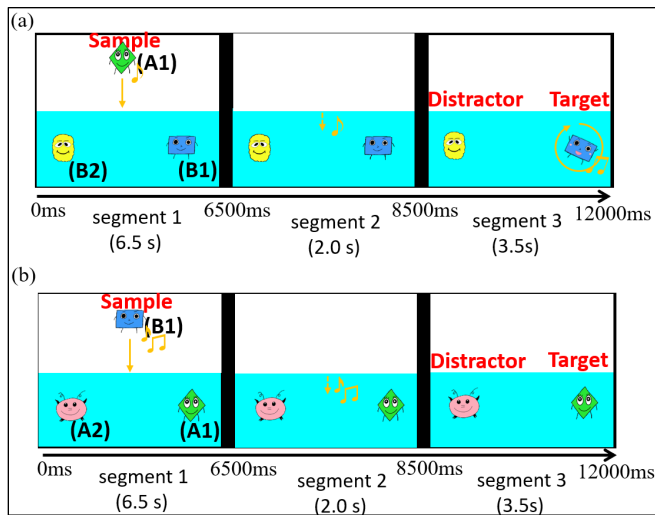

Figure 3: The stimuli and protocol for (a) familiarization (with a reward in segment 3) and (b) symmetry test (no reward in segment 3).

Procedure

The infants were tested on their caretaker's lap. The caretakers wore headphones to block sound and closed their eyes. Throughout the experiment, the pre-determined program controlled whether the current phase of the experiment was to be continued or to be ended to proceed to the next phase. However, when the infant became fussy, the experiment was interrupted manually, and an attention getter was provided. If the infant's attention could not be recovered by the attention getter, the experiment was terminated by the experimenter.

Results

Heatmap

To grasp where on the monitor the infants were attending through the time course of the experiment, the looking data from 31 infants during the symmetry test were aggregated and segmented into bins of 50 milliseconds. A heatmap was created by plotting the location of each infant's eye gaze in each bin. Although the actual locations of the target and the distractor were counterbalanced across trials, the looking of the target/distractor were transformed so that we can see whether infants were looking at the target or the distractor at a given moment. Figure 4 shows that infants were mostly following the falling object (B1/B2) while it was visible. When it became invisible behind the screen (6500 msec from the onset), infants' attention was divided between the target and the distractor. On a closer look, however, infants' gaze to the target gradually increased and peaked around 8500 ms from the onset, where the target started to move in the familiarization phase.
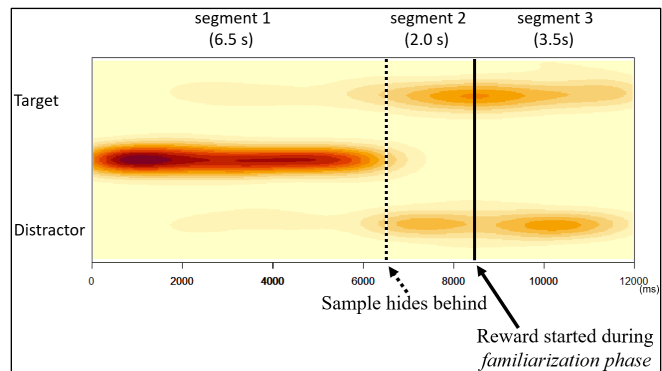

Figure 4: A heatmap showing the concentration of the gaze through the trial.

Mean looking time in the 1000 window around the reward onset in the familiarization phase

To confirm the above observation from the heatmap holds statistically, the average looking times to the target and the distractor in the 1000 ms. window around the reward onset (8000-9000 ms. from the onset of the symmetry test trial) were calculated for each infant and submitted to a t-test (Figure 5). The results showed that infants indeed looked at the target (M = 488.71 ms., SE = 71.08) longer than the distractor (M = 254.84 ms., SE = 55.91), $t(30) = 2.13$, $p = 0.041$, effect size r = 0.362, Cohen's d = 0.660. These results confirmed the presence of the contingency symmetry bias in human infants before they start active word learning. The pattern of infants' eye gaze also suggest that they can precisely predict the timing of the reward and which object would produces it.
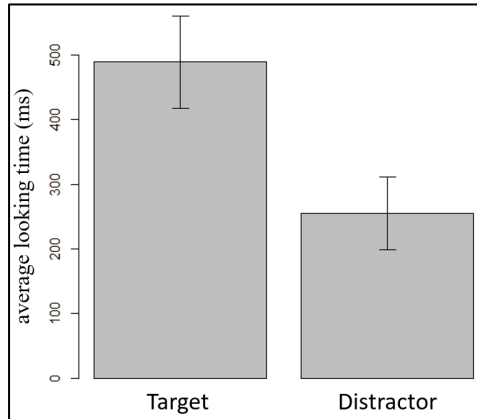
Figure 5: Average looking times at the target and the distractor in the window in which the reward was expected (8000-9000 ms. from the onset of the symmetry test trial).

Discussion

In the animal cognition literature, it has long been accepted that non-human animals are extremely resistant to generalize a learned contingency to the reversed direction (e.g., Dugdale & Lowe, 2000; Lionello-DeNolf, 2009; Sidman et al., 1982; Tomonaga et al., 1991; Völter & Call, 2017; Yamamoto & Asano, 1995; Yamazaki et al., 2008). In contrast, this bias is very common and ubiquitous in human thinking and reasoning (Kahneman et al., 1982; Hastie & Dawes, 2001; Kahneman & Egan, 2011; Oaksford, 2008).

The origin of this bias is profoundly relevant to the origin of language acquisition (e.g., Dugdale & Lowe, 2000; Horne & Lowe, 1996; Oaksford, 2008; Tomonaga et al., 1991; Yamamoto & Asano, 1995). Recently, Imai and colleagues (2021) addressed whether the bias emerges through repeated word learning experiences or whether it is present in children before they begin active word learning. Imai et al. provided evidence that infants who are still at the pre-semantic stage of language learning possess this bias (Stager & Werker, 1997). However, while Imai et al. tested the contingency symmetry bias in a temporal sequence, the matching-to-sample (MTS) paradigm is more directly relevant to word leaning.

This research examined whether the same aged infants would show the contingency symmetry bias on a MTS task, which has been used by researchers of animal cognition who investigated whether non-human animal species can learn meanings of words beyond mere object $\rightarrow$ symbol associations in one direction. The results showed the possession of the contingency symmetry bias in 8-mont-old infants on the MTS task, the task in which many years of research in animal cognition repeatedly failed to demonstrate the bias in non-human species.

The contingency symmetry inference itself is a rudimentary form of abductive inference (Völter & Call, 2017), as infants need to generalize the association between an object and a symbol they learned in one direction to the other direction. However, the role of this bias is not limited to establishing bidirectional relations between a word form (sound or sign) and an object. Sidman and colleagues (Sidman & Tilby, 1982; Sidman et al., 1982) proposed that the contingency symmetry bias can be developed into more advanced forms of inference, when it is combined with other types of inference such as transitivity inference, thereby further relations can be learned without direct training. Suppose two contingency relations, "If A, then B" (AB) and "If B, then C" (BC), are taught to a child. By making the transitivity inference, the child spontaneously forms a new relation: "If A, then C". If the symmetry inference is available, the child can additionally learn three relations: B→A and C→B, and C→A. In the end, children can learn 6 relations when only two relations are taught. This type of learning may underlie the rapid and efficient word learning in human children.

Indeed, researchers have noted that the ability to form stimulus equivalence is a prerequisite for understanding the symbolic nature of words and making inferences about word meanings (Oaksford, 2008; Wilkinson & McIlvane, 2001; Yamazaki et al., 2008). Given that the contingency symmetry bias is necessary for the formation of stimulus equivalence, the lack of this bias in non-human animals may be one of the key reasons why only humans have language. The contingency symmetry bias thus should be added to the list of key abilities (or biases) for word meaning acquisition.

Acknowledgments

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