


Do ‘literate’ pigeons (*Columba livia*) show mirror-word generalization?

Damian Scarf¹  · Michael C. Corballis² · Onur Güntürkün³ · Michael Colombo¹

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Abstract Many children pass through a mirror stage in reading, where they write individual letters or digits in mirror and find it difficult to correctly utilize letters that are mirror images of one another (e.g., b and d). This phenomenon is thought to reflect the fact that the brain does not naturally discriminate left from right. Indeed, it has been argued that reading acquisition involves the inhibition of this default process. In the current study, we tested the ability of literate pigeons, which had learned to discriminate between 30 and 62 words from 7832 nonwords, to discriminate between words and their mirror counterparts. Subjects were sensitive to the left–right orientation of the individual letters, but not the order of letters within a word. This finding may reflect the fact that, in the absence of human-unique top-down processes, the inhibition of mirror generalization may be limited.

Keywords Mirror generalization · Reading · Pigeon · Vision · Comparative cognition

Introduction

In a recent study, we successfully trained pigeons to discriminate between four-letter words and four-letter strings that only resembled words (Scarf et al. 2016). Rather than simply learning the words through rote memorization, four aspects of the pigeons’ performance suggested they were sensitive to the statistical properties that defined words. First, the pigeons’ accuracy on words correlated with their bigram frequency, a measure of the frequency with which certain letter pairs appear in the words in one’s vocabulary. Second, with respect to nonwords, the pigeons’ accuracy was related to their orthographic similarity to words (Yarkoni et al. 2008). Third, the pigeons displayed the transposed-letter effect, in which words with the internal characters transposed are misclassified as words. Fourth, the pigeons classified novel words at a level significantly above chance.

Another marker of literacy acquisition in humans is the ability to suppress mirror generalization (Ahr et al. 2016). Mirror generalization appears to be an inherent property of the visual system, allowing us to generalize from a stimulus to its mirror image (Corballis and Beale 1970; Dehaene et al. 2005). When it comes to reading, this process presents a problem (Dehaene 2009). For example, some letters (e.g., b and d) and, therefore, some words (e.g., herb vs. herd) can only be correctly identified if we are sensitive to their left–right orientation. Most children evidence this difficulty by passing through a mirror stage in which they confuse the left and right orientation of individual letters and words (Cornell 1985).

Given that our pigeons display several markers of orthographic processing, they are well perched to address whether learning to discriminate words from nonwords, independent of human-unique top-down processes (e.g., phonological representations) (Pegado et al. 2014), is

✉ Damian Scarf
damian@psy.otago.ac.nz

✉ Michael Colombo
colombo@psy.otago.ac.nz

¹ Department of Psychology, University of Otago, Dunedin, New Zealand

² School of Psychology, University of Auckland, Auckland, New Zealand

³ Department of Psychology, Institute of Cognitive Neuroscience, Biopsychology, Ruhr-University Bochum, 44780 Bochum, Germany

sufficient to inhibit mirror generalization. Critically, much as in humans, mirror generalization is also a property of the avian brain (Beale et al. 1972; Mello 1965; Watanabe 1975, 1979). To see whether, as a result of extensive training with words and nonwords, our pigeons had developed the ability to discriminate letters and words from their mirror counterparts, we presented them with mirror-word probe trials.

Materials and methods

Subjects

The subjects were the four pigeons (*Columba livia*) from Scarf et al. (2016). The current study was conducted after several additional months of training following the final manipulation (the transposition test) reported in Scarf et al. (2016). Each pigeon was maintained at 85% of its free feeding weight for the duration of the experiment. Grit and water were provided ad lib. The room in which the birds were housed was maintained at 20 °C. Overhead fluorescent lights were turned on daily at 7:00 a.m. and turned off 12 h later.

Apparatus and stimuli

Subjects were trained in one of four standard operant chambers. The front wall of each chamber housed a Perspex panel with five apertures. The center square aperture measured 3.3×2 cm and was encircled by four circular apertures, each 2.5 cm in diameter. The center-to-center measurement was 5 cm for the left and right circular apertures and 2.75 cm for the upper and lower apertures. Only the center square and the upper and lower circular apertures were used in the current study. Sitting behind the Perspex panel was a Philips 170B 17-inch computer monitor that was used to display the stimuli. Positioned between the Perspex panel and computer monitor was Carroll Touch infrared touch frame (EloTouch, baud rate 9600, transmission time 20 ms) used to record responses. Wheat was made available via a food hopper, built in house, located at the front of the box, 21 cm below the center square aperture. A ventilation fan was housed in the rear of each chamber and provided background noise of 80 dB to mask all extraneous noise.

The word and nonword stimuli consisted of four-letter strings in Arial 12-point font bold. Words were drawn from the pool of 308 words and nonwords from a pool of 7832 stimuli. Both sets were drawn from Grainger et al. (2012). The black eight-point star used for nonword responses was 1.5 cm in diameter.

Training

Word and nonword stimuli were presented in the center square aperture. The star stimulus was simultaneously displayed in either the upper or lower aperture. When a word was presented in the center aperture, the correct response was to peck the word. When a nonword was presented in the center aperture, the correct response was to peck the star stimulus. The location of the star stimulus was randomized across trials. After a correct response, pigeons were provided with a 1.2-s access to wheat, followed by a 5-s inter-trial interval (ITI). An incorrect response resulted in the immediate termination of the trial and a 5-s time-out period that preceded the ITI. A correction procedure was used throughout training, such that after an incorrect response, the trial was repeated until the subject made the correct response.

For the first word, a session consisted of 50 word trials and 50 nonword trials. The 50 nonword trials consisted of the presentation of 50 nonwords drawn from a pool of 7832 nonwords used by Grainger et al. (2012). The nonwords were drawn randomly for each session. Once a subject achieved the training criterion, a second word was added. For the second word, a session consisted of 25 trials of the new word (i.e., the second word) and 25 trials of the old word (i.e., the first word) and 50 nonword trials. From the third word to the 25th word, each session consisted of 25 trials of the new word, 25 trials of the old words, and 50 nonword trials. For example, when a subject was on their sixth word, the session consisted of 25 trials on the sixth word, 5 trials on each of the old words (i.e., 25 trials total), and 50 nonwords. When the number of old words was not evenly divisible into the 25 trials, some old words, selected at random, appeared more frequently than others. From the 26th word onward, each old word was presented once per session. Initially, the number of nonword trials was maintained at 50, irrespective of the number of words a subject had learned; however, this was later changed such that the number of nonword trials increased in concert with the number of word trials. For example, when subject Q43 was on its 57th word, a session consisted of 25 trials on the new word, one trial on each of the 56 old words, and 81 nonwords.

To reach criterion on a word, a subject had to perform at $\geq 66\%$ on both the new word and the nonwords across two consecutive sessions. In addition, on the second criterial day, a subject needed to perform $\geq 66\%$ on the old words. Subjects had acquired between 30 and 62 words at the time they were tested with mirror words (subject Q32: 30 words, subject Q35: 60 words, subject Q41: 32 words, and subject Q43: 62 words).

Testing

Mirror words were presented as nondifferentially reinforced probe trials. Subjects were presented with either 4 (Q32 and Q41) or 8 (Q35 and Q43) mirror-word probes per session, and the total number of mirror-word probes matched the number of words the subject had acquired. When the number of mirror-word probes was not evenly divisible by the number of probes presented per session, some mirror words were repeated in the final session to fulfil the 4 or 8 probe trials. Importantly, only the first presentation of each mirrored word was included in the analysis. The stimuli were created by simply mirror-reversing the training stimuli.

Results

Performance was calculated as the proportion of trials on which subjects made a word response for words, non-words, and mirror words. An analysis of variance (ANOVA) with repeated measures across trial type was significant, $F(2, 6) = 40.67$, $p = .001$, $\eta_p^2 = .93$ 95% confidence interval (CI) = [0.50, 0.96]. Post hoc pairwise comparisons (with Bonferroni correction) revealed that subjects made significantly more word responses on word trials than nonword and mirrored word trials, with the latter two not significantly different from one another (Fig. 1a). To assess whether subjects' mirror discrimination abilities extended to the word as a whole, independent of the orientation of individual letters, we assessed their performance as a function of the number of asymmetrical (e.g., R, S, etc.) and symmetrical letters (e.g., A, T, etc.) a word contained. Given that the number of mirror words in some categories was very low

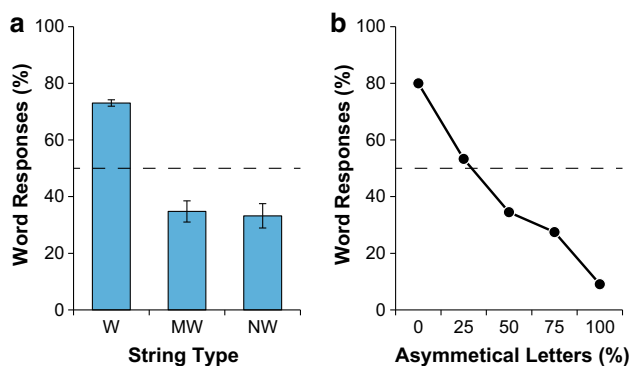


Fig. 1 Mean percentage of word (W), mirror word (MW), and nonword (NW) trials on which subjects made a word response (a) and performance on mirror words as a function of the number of asymmetrical letters they contained (b). Error bars represent ± 1 standard error of the mean

(e.g., across all four birds only five mirror words contained no asymmetrical letters), we pooled the data across subjects (Fig. 1b). The birds' performance was clearly controlled by the proportion of asymmetrical letters, with words with no asymmetrical letters (e.g., ATOM) largely classified as words (4 out of 5 instances or 80%) and words containing all asymmetrical letters (e.g., JERK) rarely classified as words (1 out of 11 instances or 9%). A Cochran–Armitage χ^2 test confirmed that the percentage of word responses significantly decreased as a function of the number of asymmetrical letters a word contained, $p < .001$.

Discussion

The fact that subjects classified mirror words with all symmetrical letters as words, but rarely classified mirror words with all asymmetrical letters as words, suggests subjects were sensitive to the left–right orientation of the individual letters (e.g., R vs. Я), but not the order of letters within a word (e.g., ATOM vs. MOTA). This finding may reflect the fact that, in the absence of human-unique top-down processes, the inhibition of mirror generalization is limited to the level of individual letters. An alternative possibility is that, when presented with the mirror words, pigeons reverted to their natural tendency to focus on the local features of the words rather than the more global properties (Cavoto and Cook 2001). Finally, it is possible that, in mirror form, words with all symmetrical letters still contained high-frequency bigrams. That is, rather than subjects viewing a word (e.g., ATOM) and their mirrored counterpart word (e.g., MOTA) as equivalent, subjects may have processed the latter as a novel word and classified it according to the frequency of the bigrams it contained.

The current study provides further evidence that some, but perhaps not all, components of humans' ability to process the visual word form rely on processes in the visual cortex that are widespread in the animal kingdom. Whether, as in humans, these processes are localized in a specific area of the visual cortex will require us to look inside these bird brains.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This research was approved by the University of Otago Animal Ethics Committee.

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