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OUTLOOK

Orthographic processing in animals: Implications for comparative psychologists

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Summary Two recent studies have shown that pigeons and baboons can discriminate written English words from nonwords, and these findings were interpreted as demonstrating that orthographic processing is possible in absence of linguistic knowledge. Here, I emphasize a different idea, which is that these studies also inform comparative psychologists on the evolutionary history of statistical learning in nonhuman animals, and on its pervasiveness and flexibility.

Keywords Attention · Comparative cognition

Scarf et al. (2016) recently showed that pigeons can be trained with touch screens to discriminate real English words from letter strings that are not words and can furthermore successfully sort novel word and nonword stimuli never seen before, after training. They also reported that the accuracy for nonword letter strings depended on their orthographic distance to words: Nonsense words for which this distance was minimal tended to be classified more often as words. These two results extend to pigeons the findings of Grainger, Dufau, Montant, Ziegler, and Fagot (2012), who had shown that baboons can be trained to distinguish words from nonwords by considering their orthographic properties. It was concluded from these two studies that prior linguistic knowledge is not a prerequisite to achieve humanlike orthographic processing (Grainger et al., 2012); that orthographic processing can be achieved with a brain architecture, and visual system, very different from humans (Scarf et al., 2016); and more broadly that orthographic processing recycles general visual mechanisms preexisting in nonhuman animals (Grainger et al., 2012; Scarf et al., 2016). The conclusion that a nonhuman animal species can demonstrate orthographic processing has received much attention from the general public and has also been amply discussed in the scientific literature. Some adhere to this conclusion while others are more skeptical. Here, I would like to discuss these two studies from a different standpoint.

Developing open-ended strategies for discriminating words from nonwords is not an easy task at all. It requires at least that the letters (i.e., the unit composing the words) be processed and discriminated. This first layer of analysis was clearly demonstrated in pigeons and baboons who classified as nonwords letters strings in which letters from real English words were substituted by other perceptually similar letters. However, an analysis of the letter strings limited to letters does not suffice to discriminate word from nonwords, and this categorization also requires an orthographic code based on the relative frequency of the letters, or combination of letters, within the words. This second layer of analysis was also discovered in both pigeons and baboons: these two species treated nonwords created by transposing the letters (casino vs. caniso) of real words more like words, in comparison to control words in which two letters were substituted by two other letters of the same vowel or consonant category (e.g., caviro, transposed-letter effect; Scarf et al., 2016; Ziegler et al., 2013). This "transposed letter" effect demonstrates that the processing of the words by pigeons and baboons is not limited to the encoding of specific letters in some specific positions but also involves a more flexible encoding of the letter combinations at the level of the word. Said differently, pigeons and baboons have demonstrated in these studies an amazing ability to process the words at different stimulus levels and to flexibly combine the information at these levels to discriminate English

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words from nonwords. These two levels of processing are considered as hallmarks of orthographic processing in humans and are therefore apparently shared by the three different species (pigeons, baboons, and humans).

One interesting aspect of these studies is the fact that letter strings have no immediate ecological validity for pigeons and baboons: There are no letters in the pigeons' or baboons' natural words. This contrasts with literate humans, who use letters of the alphabet and written words to communicate with the other members of their species, and who have also been trained to process written words from a young age. Moreover, pigeons, baboons, and humans have different ecological niches, different brains, different visual systems (at least in pigeons), and are phylogenetically separated by more than 300 million years of divergent evolution. Therefore, one may wonder why such a high level of similarities emerged across such diverse species, especially in such a complex task involving the processing of word and nonword stimuli.

I propose here that this convergence reflects the fact that the discrimination of words versus nonwords recruits two widely spread mechanisms, which are, first, the ability to discriminate visual items and second, the ability to process the statistical regularities among these items. Statistical regularities in time and space are defining features of the world. Dealing with such statistical regularities is probably a function that many species (at least those who adapt their behavior through learning mechanism, like pigeons, baboons, and humans) must develop for survival, whatever the specificities of their ecological niche, biology, or evolutionary history. All the convergent findings reported above in pigeons, baboons, and humans underline the need for these species to develop domain-general functions aimed at detecting statistical regularities in many different types of input, even the most unnatural ones (as written words can be for pigeons or baboons). They moreover suggest that the need to detect and process statistical regularities is an organizational principle for a vast range of cognitive systems, in both humans and nonhuman animals.

But pigeons are not baboons, no more than baboons are humans. Humans read; neither baboons nor pigeons do. There are therefore good reasons to think that subtle differences will be discovered among these species, if their strategies are examined in more detail. First, the processing of statistical regularities implies that the subject process the information at the level of the unit that is perceived (e.g., the letter) and at a more global level for inferring the statistical distribution of these units. There remains the possibility that the different species do not weigh these two levels of information equally, some giving more importance to the processing of the unit over their statistics, or vice versa. Second, evidence suggests that the learning of statistical regularities in spatially (e.g., Grainger et al., 2012) and temporally organized stimuli (Minier, Fagot, & Rey, 2015) uses in priority the transitional probability between (temporally or spatially) adjacent items. But statistical regularities within such stimuli may also require that nonadjacent associations are detected and processed, for instance, when Event A is associated with Event B, despite one or several intervening events (for instance, in the A × B sequence). The processing of nonadjacent dependencies is more demanding in terms of working memory resources than the processing of adjacent dependencies. Because of this difference in memory constraints, one can also reasonably expect that all species are not equally efficient at processing long distance dependencies, and therefore that they do not necessarily consider the same primitives for computing statistical regularities within sets of items. Finally, species are also probably not equally adept at processing distributional statistics, even if they do not differ regarding the two potential issues mentioned above. Studies on orthographic processing in pigeons and baboons showed, for instance, that pigeons were sensitive to bigram frequencies, in contrast to one baboon (at least), which considered trigrams frequencies (Hannagan, Ziegler, Dufau, Fagot, & Grainger, 2014) to categorize words from nonword letter strings.

Real comparative experiments in which different species are tested with the same experimental design are relatively rare, and even more so when the task requires advanced forms of cognitive processing. These experiments on orthographic processing in animals demonstrate the potential of this approach. In that case, Scarf et al. (2016) confirmed in pigeons the generalizability of the findings already obtained on baboons by Grainger et al. (2012), and these two studies make it clear that a cognitive competence (orthographic processing) which appears to be, at first glance, a highly specialized and cultural specific function, recruits, in fact, some mechanisms that are widely spread in the animal kingdom. Comparisons across species have further highlighted the adaptive value, flexibility, and pervasiveness of statistical learning in nonhuman animals. There is much to learn on the evolution of cognition in nonhuman animal species, and on the specificities of human cognition, if these comparative issues are explored further, in line with Scarf et al. (2016).

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