

Constraints on the lexicons of human languages have cognitive roots present in baboons (*Papio papio*)

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Abstract

Using a pattern extraction task, we show that baboons, like humans, have a learning bias that helps them discover *connected* patterns more easily than disconnected ones, i.e. they favor rules like ‘contains between 20% and 60% red’ over rules like ‘contains less than 20% or more than 60% red’. The task was made as similar as possible to a task previously run on humans, which was argued to reveal a bias that is responsible for shaping the lexicons of human languages, both content words (nouns and adjectives) and logical words (quantifiers). The current baboon result thus suggests that the cognitive roots responsible for regularities across the content and logical lexicons of human languages are present in a similar form in other species.

Keywords: connectedness, human languages and their lexicons, primate semantics

1 Connectedness: constraints on natural classes and pattern extraction

Humans and animals categorize objects in the world into natural classes based on various criteria. A prominent example of a criterion that has been hypothesized for humans is *connectedness*. Informally, connectedness requires that whenever two objects *a* and *c* belong to a certain class, and a third object *b* is ‘between’ *a* and *c*, then *b* must also belong to that class. The traces of connectedness are twofold. First, content words (nouns and adjectives) in the world’s natural languages are generally connected (Gärdenfors, 2004). For example, the set of all flying, feathered animals is a natural, connected class, for which many languages have a single word (e.g. *bird*); however, the set of all objects that are either red or a bird is not a natural class—it is too disconnected (e.g. it includes both raspberries and bluejays, but not blueberries)—and indeed no language has a single word meaning ‘red or bird’. Second, connectedness creates a learning bias: new nouns are preferably associated with connected meanings than with non-connected ones (Dautriche and Chemla, 2016; Xu and Tenenbaum, 2007).

Recently, Chemla et al. (2018) have generalized the notion of connectedness to the domain of logical words, specifically quantifiers. They show that connectedness is a weak version

of *monotonicity*, a classic notion in formal semantics: a quantifier q is monotonic just in case both q and its negation are connected. Examples of monotonic quantifiers include *somebody*, *everybody*, and *more than five people*. Connected but non-monotonic quantifiers include *some but not all people* and *between three and five people*. Non-connected quantifiers include *all or no people* and *fewer than three or more than five people*. As in the domain of content words, connected quantifiers appear to be privileged across the lexicons of the world’s languages: most lexicalized quantifiers are connected, if not monotone, and conversely, non-connected concepts generally require compositional machinery to be expressed (e.g. via overt disjunction, or with the help of a non-connected content word, as in *an odd number of people*; see Keenan and Paperno, 2017 for a survey). Furthermore, Chemla et al. show that humans have corresponding learning biases favoring connected quantifiers, as evidenced by performance on rule learning, or pattern extraction, tasks: it is easier to discover connected rules than non-connected ones, and easier still to discover monotone ones.

A natural hypothesis is that the source of the regularity of the world’s lexicons, for both content and logical words, is a learning bias for connectedness. Can the roots of this bias be found independently of language proper, and do other animals show the same bias? The object/noun version of the connectedness constraint has been explored with animals, often under the name of pseudo-categorization (e.g. Wasserman, 2016; Zentall et al., 2008). Here, we report on an experiment that explores the rule/quantifier version of connectedness with animals. We presented baboons with a pattern extraction task, which is as close as possible to the task used to argue for a human learning bias favoring connected quantifiers. We do not need to wonder whether this requires high-level reasoning abilities (Call, 2006; Tomasello, 2014), and surely there is no claim that a ‘word’-like element has this high logical type in an animal’s repertoire. We thus ask whether the connectedness constraint is active for an animal’s *potential* ‘functional vocabulary’. If the answer is positive, it may suggest that the shape of the world’s lexicons, including logical lexicons, has roots in general, non-linguistic cognitive biases, which may have evolved in other animals, too, independently of language.

2 Method

The data and the script for their analysis are available here: <https://tinyurl.com/y96bctb5>.

Ethical standards. This research conformed to the Standard of the American Psychological Association’s Ethical Principles of Psychologist and Code of Conduct, and received ethical approval from the French Ministry of Education (approval APAFIS #2717-2015111708173794 v3).

Participants and apparatus. 13 Guinea baboons (*Papio papio*, 10 females; age range: 2-20 years) from the CNRS primate facility (Rousset-sur-Arc, France) participated in the study. An additional 10 participants started the study but were not included in the final sample because they did not reach the learning criteria for the first condition they were assigned in (see Inclusion criterion below). This is the maximal number of participants that we could test. The participants were tested using ten automatic computerized learning devices for monkeys (see Fagot and Bonté, 2010), each comprising a touch screen and food dispenser, which were freely accessible from the baboons’ living enclosures. The procedure used an automated radio frequency identification of the subjects within each test system, making it possible to test the individuals without capturing them. Use of this procedure improves animal welfare in experimental research (Fagot et al., 2013).

Stimuli. There were 3 sets of 6 stimuli, represented in Table 1. A stimulus was a picture of a circle filled by $X\%$ of a color α and by $(100 - X)\%$ of a color β on a black background. X had 6 possible values (0, 20, 40, 60, 80, 100), such that each stimulus in its set may be described by its proportion of color α . The 3 stimuli sets differed in the α/β colors they featured (i.e. white/purple; orange/blue; pink/grey), in the orientation of the line separating the two colors (i.e. horizontal, diagonal, vertical), and in the set of two response buttons provided to the participants to arrange the stimuli in two groups. Each response button featured a yellow digit on a black background. All participants saw the three sets of stimuli in the same order, but associated with different conditions. Each image was created as a bitmap file with 250×250 pixels and presented on the screen as a square of 6cm, corresponding to a visual angle of 11.4° at a distance of 30cm.

























	Displays						Response buttons	
	0%	20%	40%	60%	80%	100%	(comparison stimuli)	
Set 1								
Set 2								
Set 3								

Table 1. Each stimulus was a circle characterized by the proportion of color α (e.g. for set 1, white vs. purple) of its total area, varying from 0% to 100% by increments of 20. Each set was presented with a different pair of response buttons (i.e. arbitrary digits).

Task and conditions. Participants were tested in a matching-to-sample task: in each trial an item selected from a given stimulus set was used as a sample, and two distinctive shapes A and B (i.e. digits) as comparison stimuli. The task was to learn a rule where half of the 6 stimuli in a set correspond to a response A, and the other half to a response B. There were 3 conditions, described schematically in Table 2. In the *monotone* condition, the 3 stimuli associated with A were clustered at one extreme (and the stimuli associated with B were thus clustered at the other extreme). In the *connected* condition, the 3 stimuli associated with A were all contiguous, but not clustered at an extreme. Finally, in the *non-connected* condition, the 3 stimuli associated with A were spread non-continuously, and so were the stimuli associated with B.

The 3 conditions were implemented in a different order to three different groups of participants. The order of the conditions was determined such that group 1 saw the conditions in increasing order of difficulty (*a priori*), group 2 in decreasing order, and group 3 started with the connected condition so that all conditions occurred first across groups. The stimuli sets were implemented in the same order to the different participants (so that they would be matched with different conditions across groups).

Procedure and learning criteria. Stimuli were presented in blocks of 6 trials containing all proportions, with random order within each block. A trial started with the presentation of a stimulus centered in the middle of the screen. Once participants touched the stimulus picture, the two response buttons A and B appeared on each side of the screen. The left-right location of the response buttons was fixed within each learning condition. Touching the correct button cleared the screen and delivered a food reward. Touching the incorrect button triggered a 3-second timeout

Conditions	0%	20%	40%	60%	80%	100%
Monotone	A	A	A	B	B	B
Connected	B	B	A	A	A	B
Non-connected	B	A	A	B	B	A

Table 2. The 3 conditions were determined by whether a particular stimulus should be matched with the first response button (A) or the second response button (B). Monotonicity and connectedness of the resulting pattern are determined based on the way the As and Bs are entangled.

indicated by a green screen. Participants were allowed a maximum of 5 seconds to respond. The inter-trial interval was set to 3 seconds. A rule was considered to be learned when the participants made no more than 1 error per block for three consecutive blocks (a general accuracy criterion), and no 2 of such errors were on the same stimulus (to ensure that each item could be counted as learned).

Inclusion criterion. We included all participants who learned at least one rule and in our analysis only considered the rules for which the learning criteria were reached. Of the 13 participants included in our sample, 9 participants (3 per group) learned the 3 proposed rules (one in each condition), 2 learned 2 rules (connected and monotone), and 2 learned a single rule (one in the non-connected condition and the other in the monotone condition). Excluding participants who did not finish the experiment (i.e. who could not reach the learning criteria in each of the 3 proposed conditions) does not change the pattern of results.

3 Results

We reproduced the two analyses already used in a human version of the task (Chemla et al., 2018).

Analysis 1: Learning performance. Participants took on average 2,888 trials to reach the learning criteria across conditions ($SE_{trials} = 330$; $min_{trials} = 162$; $max_{trials} = 7,392$). Figure 1 reports the average number of blocks of trials needed to learn a rule per Condition (monotone, connected, and non-connected).

To quantify the ease with which different rules are learned, we fit the number of blocks of 6 trials needed to learn the rule using a mixed model in R (lme4 package, Bates et al., 2015). The model included a categorical predictor Condition (monotone, connected, non-connected) as well as a random intercept for each Participant. The model was specified as: $Nblocks \sim Condition + (1 | Participant)$ and compared to a model without the predictor Condition to establish the effect of connectedness on learning difficulty.¹ Condition was a significant predictor of learning performance ($\chi^2(2) = 16.76$; $p < 0.001$) with the monotone and the connected rules learned the fastest ($M_{monotone} = 367$ blocks; $SE_{monotone} = 75$; $M_{connected} = 319$ blocks; $SE_{connected} = 66$) and the non-connected rule learned the slowest ($M = 741$ blocks; $SE = 70$).²

¹ Since adding a predictor Condition Order (and its interaction with Condition) did not improve the model fit significantly ($\chi^2(4) = 6.96$; $p = 0.14$), this predictor was removed from the final model.

² In some cases the non-connected rule could not be learned at all: 2 participants did not succeed in reaching the learning criteria in the non-connected condition despite receiving a high number of blocks (> 1675) and despite succeeding in learning in the two other conditions. Note that these two unfinished learning conditions are not included in our analysis (see Inclusion criterion).

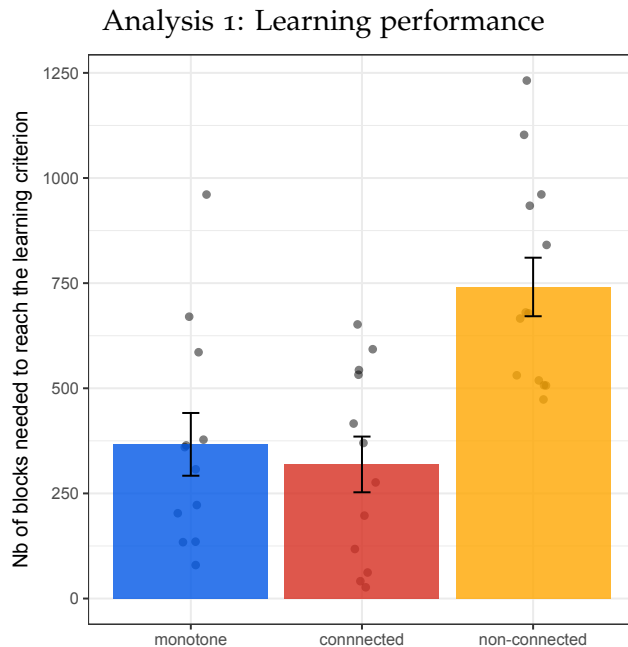


Figure 1. Results corresponding to Analysis 1: The Figure represents the average number of blocks needed to reach the learning criterion for each Connectedness condition (monotone, connected, non-connected). Error bars indicate standard errors of the mean. Dots represent individual data points.

Analysis 2: Bias for connectedness. To quantify the role of connectedness independently of the conditions in which participants were tested, we inspected the responses within all blocks of trials and asked whether these responses correspond to a connected guess about the underlying rule. For this, we looked at whether participants’ response for a stimulus (characterized by $X\%$ of its area colored) is dependent on their responses for the two ‘contiguous’ stimuli (filled by $X - 20\%$ and $X + 20\%$ of the same color) within the same block of trials. The idea is that if participants responded in one way to both $X - 20\%$ and $X + 20\%$, they should respond in the same way to the central case $X\%$. We modeled participants’ A response (coded as 0/1) for a given stimulus using a mixed logit model specified as $\text{response} \sim \text{NContiguousResponses} + \text{Condition} + (\text{NContiguousResponses} + \text{Condition} \mid \text{Participant})$ ³ where the predictor NContiguousResponses is the sum of responses A (0 to 2) for both contiguous stimuli within the same block.

As can be seen in Figure 2, there was a significant effect of responses to the contiguous stimuli on the response participants gave ($\chi^2(2) = 14.79$; $p < 0.001$): participants were more likely to give a response A when they responded A to both contiguous stimuli than if they responded A to only one of them ($\beta = -0.80$; $z = -6.35$; $p < .001$), in which case they were at chance, or to none ($\beta = -1.41$; $z = -5.96$; $p < .001$), in which case they were more likely to respond B. This was presumably true in all three conditions (there was no effect of Condition, $\chi^2(2) = 2.39$; $p = 0.30$, despite the presence of feedback inducing participants’ response towards connectedness or non-connectedness).

4 Discussion

The meanings of words in natural languages are, by and large, subject to a connectedness constraint. This constraint could be the fossilization in language of more general, non-linguistic

³ A model with the interaction between NContiguousResponses and Condition did not converge.

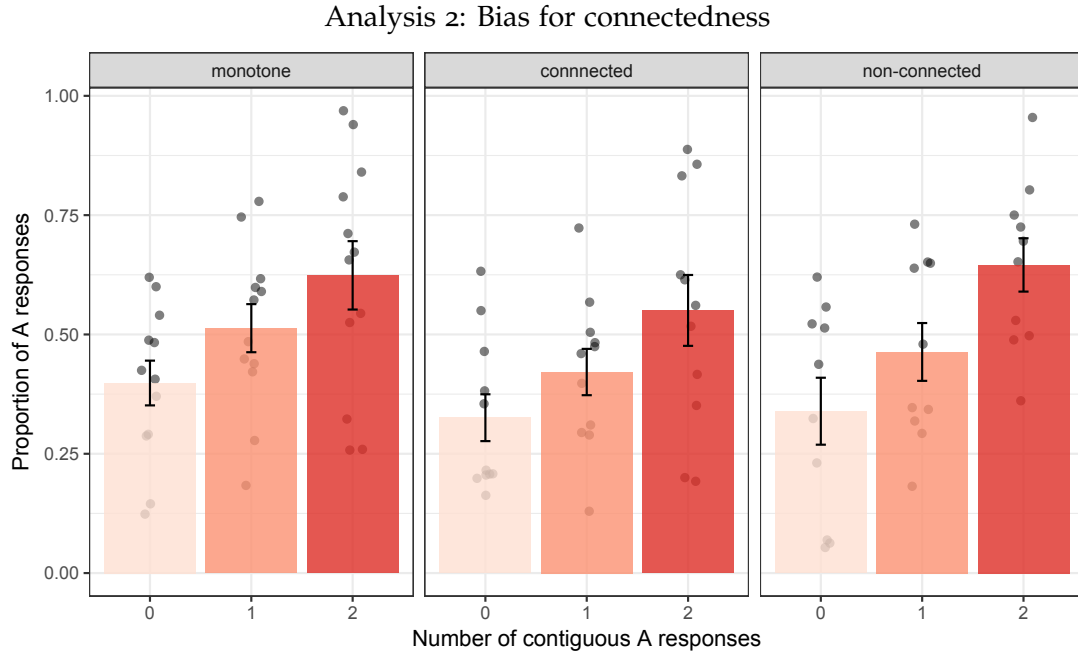


Figure 2. Results corresponding to Analysis 2: The Figure represents the proportion of A responses as a function of the number of A responses given on the contiguous stimuli. Error bars indicate standard errors of the mean. Dots represent individual data points.

biases: in a large hypothesis space for the meaning of a new word, connected meanings are at an advantage because the patterns they correspond to are more salient to humans. These biases, which apply to both content and logical words (Chemla et al., 2018), could be present even in animals without an extended lexicon (Schlenker et al., 2016). In this study, we provide evidence that baboons, just like humans, find it easier to discover connected patterns than non-connected patterns. The connectedness constraint is thus active in these species in a form that can explain how the referential and functional lexicons of human languages are shaped.

Finally, in addition to helping us understand the nature of human lexicons, the evidence we found for baboons' biases towards connectedness may also shed light on the nature of animals' own lexicons, too. When seeking to find the meaning of a new word in a new language, we may rely on our intuitions about what a word could mean in general, and in particular restrict attention to connected meanings. When studying animal communication systems — in simple cases, trying to make sense of a given call from a species that may be very different from ours — we should be as cautious as possible with our intuitions. However, if we are correct that the same biases that let connected words spread in humans' lexicons are present in animals, then this result can be used (still, with caution) to favor some meanings, or conditions of use, over others for our hypotheses about animals' calls. A striking example can be found in Schlenker et al. (2016): researchers have been led to postulate that monkey calls enter in competition with one another, a rather high-level competence *a priori*. This possibility was actually raised in large part to avoid postulating meanings of individual calls that would not be intuitively simple, which in effect meant not connected. Put differently, one could hesitate between two theoretical options: allowing for non-connected meanings, or postulating that animals have access to higher-level linguistic mechanisms. Showing that connectedness is a respectable desideratum for animal communication systems may contribute to a proper evaluation of such theoretical possibilities and supplement (in this case, confirm) our intuitions, which may otherwise be misplaced for animals.

Author contributions

B. B., E. C., and I. D. developed the study concept. J. F. adapted it to non-human primates, wrote the test program, and performed the testing and data collection. I. D. performed the data analysis. B. B. and E. C. wrote the introductory and discussion sections of the manuscript, and I. D. wrote the method and results sections. J. F. provided comments on initial drafts. All authors edited and approved the final version of the manuscript for submission.

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