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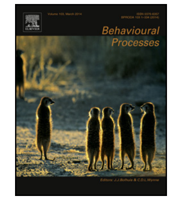

Behavioral assessment of combinatorial semantics in baboons (*Papio papio*)

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ABSTRACT

Combinatorial semantics is a core property of human language whose mechanisms remain poorly known. This study used computerized tasks with touch screens to investigate whether baboons (*Papio papio*) can understand the combination of shape and color labels in order to designate their corresponding colored shape. The baboons were trained either directly with label-pairs (Experiment 1) or with individual shape and color labels (Experiment 2), before being tested with novel compound labels from which they had to identify the referent. Compound labels understanding was found in one out of seven baboons tested in Experiment 1. Quite surprisingly, none of the 11 baboons showed this capacity in Experiment 2. We discuss several aspects of our protocols which could explain this difference between our two experiments, as well as the significance of our findings for language studies in animals and children.

1. Introduction

Language is a distinguishing characteristic of our species which is often considered an exception among animals' communication systems (Chomsky, 1959; Lenneberg, 1964; Pinker, 1994). Nevertheless, a striking number of similarities were recently found between the human language and the communicative systems of other animals, regarding for instance vocal learning (e.g., Doupe and Kuhl, 1999; Snowdon, 2009), syntactic organization of communicative signals (e.g., Ten Cate and Okanoya, 2012), the ability to produce or discriminate center-embedded patterns (e.g., Gentner et al., 2006; Rey et al., 2012), or the use of functionally referential signals (e.g., Seyfarth and Cheney, 2003). Although each of these functions have potentially independent evolutionary backgrounds, this burst of evidence demonstrates that human language probably did not emerge *de novo*, but originated from cognitive "building blocks" already present in non-human species (e.g., Wasserman et al., 2015). They further indicate that animals can serve as useful models for the study of human language learning, with the side advantage of providing unprecedented information on animal cognition (e.g., Pepperberg, 1999). The current study will focus on one of these building blocks of human language which has been largely neglected so far in animal studies, namely the ability to gain a combinatorial understanding of meaningful symbols.

Combinatorial semantics is the principle according to which the meaning of an expression is different from the sum of the meaning of the words it is composed with. This property, which is at the very core of the human language (e.g., Hurford, 2004; Marler, 1977), emerges as soon as lexicon acquisition switches from an initial stage of slow growth to a subsequent "vocabulary burst" stage: the children's initial holophrases (e.g., Bloom, 1973) quickly turn into first combinatorial two-word utterances (Brown, 1973). Combinatorial semantics is thus closely related to word learning, not only because understanding a sentence requires that its parts are also understood, but moreover because the words that children need to learn are produced within a semantic combinatorial system.

Immediately after birth, children are exposed to a continuous stream of speech from which they need to identify relevant acoustical sub-units (words) and their meaning. Children extract the meaning of words from complex sentences, in the same manner that they use statistical information to discover the boundaries of words in the speech stream (e.g., Saffran et al., 1996). Although each sentence can contain several lexical items to map onto different referents (e.g., "I should take the *dog* to the *vet*" ; "Give the *dog* its *medication*"), properties ("That's a *good old* dog!") or actions ("Did someone *feed* the dog?" ; "Please, *stop* this dog from *barking*!"), word learning benefits from this complex input thanks to an

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unsupervised learning of the co-occurrences between a word and its referent (review in Smith et al., 2014).

Another information source as to the meaning of words is provided by much simpler linguistic contexts in which a word is produced either in isolation (e.g., "Dog!") or in stereotypic sentences (e.g., "This is a dog", "Look at the dog!"). In such contexts, although the meaning of the word still needs to be interpreted, the object to which it refers is unique, thus unambiguous. For English-learning children, words produced in isolation represent from 9% (e.g., Brent and Siskind, 2001) to 12% (Aslin et al., 1996) of the input, and at least half of first child-directed utterances is drawn from a small set of simple sentence frames (e.g., Broen, 1972; Cameron-Faulkner, 2003). Words presented in isolation or embedded within stereotypic sentence-frames are thus a substantial part of the input which was shown to facilitate word learning (e.g., Brent and Siskind, 2001; Fernald and Hurtado, 2006), but they are also totally absent from several cultures (Lieven, 1994; Schieffelin, 1985) which suggests that they are not necessary for word learning.

Together, the co-occurrence of words within the linguistic contexts and more direct labeling thus provide young children two efficient ways to discover the meaning of words without prior linguistic knowledge. We can presume that these two different types of informational source are not equally efficient for learning the meaning of words, and later to comprehend combinatorial information which is inherent to complex linguistic contexts. Understanding the meaning of isolated words (e.g., "Big" and "dog") does not necessary suffice to understand their combination ("Big dog"), as suggested for example by children's difficulties with the combinations of nouns and adjectives that they otherwise understand in isolation (e.g., Ninio, 2004). By contrast, learning words from more complex expressions could facilitate the interpretation of new compounds, since words have already been learned as parts of a larger structure. However, this latter strategy could in turn be more demanding than learning highlighted target words (e.g., Fernald and Hurtado, 2006), as a consequence of the complexity of the verbal input. Thus far, for obvious practical reasons, the effect of the above two linguistic contexts on the understanding of combinatorial semantic structures has only been investigated in toddlers, in other words yet non-naïve learners. This approach exclusively centered on speaking children prevents firm conclusions on the relative efficiency of these two kinds of cues for the early understanding of word combinations.

Animals are interesting models to investigate combinatorial semantic processes. First, they are by definition language-naïve subjects. Second, they can be tested using paradigms limiting the impact of social cues, which can hardly be ruled out in children. Finally, the test of animals can indicate if the processes at stake are species-general cognitive mechanisms or language-specific (human) mechanisms. Animal language research (ALR) projects have already investigated the acquisition of a symbolic use of signs (e.g., Gardner et al., 1989; Pepperberg, 1999; Savage-Rumbaugh, 1986) or the grammatical use of these signs (e.g., Premack, 1976; Terrace, 1987) in a comparative human/animal framework (e.g., Gardner et al., 1989; Terrace, 1987). However, to the best of our knowledge, all these projects initially trained the subjects with words presented either in isolation (e.g., Gardner et al., 1989; Patterson, 1978; Premack, 1976; Terrace et al., 1979), in short and redundant sentence-frames such as "Where is the _ ?", "Look at the _" (e.g., Gardner et al., 1989; Pepperberg, 1999; Terrace, 1987), or even in rotely learned "stock" sentences (e.g., Premack, 1976; Rumbaugh, 1977). As far as we know, the only symbol (lexigram, sign or spoken word) that the animals had to map onto an object of the real world was in these researches the symbol under training. The other contextual words neither really contributed to the meaning of the whole sentence (Terrace et al., 1979) nor to the identification of the target object, given their stereotypic structure. Correct understanding of novel combinations of known words have been described in animals (e.g., Herman et al., 1984; Premack, 1976; Schusterman and Gisiner, 1988), but to our knowledge there is no published report on the very first exposure to combinations of words in naïve animals. In addition, we were unable to find a research project examining whether the animals could directly infer the meaning of lexical items from a compound input without being firstly trained with isolated words.

The current research specifically investigated in this context whether nonhuman primates could extract the independent meaning of symbols presented in combinations only (Experiment 1) and whether they could interpret new combinations of symbols learned in isolation (Experiment 2).

2. Experiment 1

Experiment 1 investigated if the baboons could learn the meaning of individual symbols, and later comprehend the meaning of novel combinations of these symbols, after being initially trained only with combinations of symbols. In other words, it aimed to determine whether "words" meaning could be inferred from complex inputs, thanks to the apprehension of the co-occurrence of these words and their referent(s) during training, and in absence of an explicit labeling of the objects.

2.1. Method

2.1.1. Subjects

The subjects were seven female Guinea baboons (*Papio papio*) from the CNRS primate facility in Rousset (France). The baboons (age range: 4.3–16.3 years) lived in a social group of 24 individuals housed in a 700 m^2 outdoor enclosure connected to an indoor animal area and two freely accessible experimental rooms. Water was provided *ad-lib* and the monkeys received their regular daily food ration every day at 5 pm. All baboons had several years of experimental history during which they were tested in a variety of computerized tasks involving touch screens.

2.1.2. Apparatus

Baboons were tested using the automated learning device for monkeys (ADLM, see Fagot and Bonté, 2010; Fagot and Paleressompoulle, 2009). This experimental system allows testing on an entirely voluntary basis by offering a 24-h access to computer-controlled operant conditioning test systems installed within the experimental rooms. Each experimental room contains five ALDM test systems, each equipped with a 19-in. touch screen, a food dispenser (rewarding correct responses with a few grains of dry wheat), and a radio frequency identification (RFID) reader which identifies each baboon via a microchip implanted in each arm. Automatic identification is used by a customized test program developed with E-Prime (Professional V. 2.0, Psychology Software Tools, Pittsburgh, PA) by the last author (JF). The test program tracks the "last stopping point" of the subject in the sequence of trials to be performed, and determines trial parameters on that basis. This procedure allows fully balanced experimental designs irrespective of the order in which the baboons spontaneously enter the test booths and the test booth they decide to use.

2.1.3. Stimuli

The stimulus set comprised nine different pairs of yellow letters (50 × 50 pixels each), thereafter called compound labels, and nine (150 × 150 pixels) geometrical colored shapes (called "objects"). The compound labels were constructed by combining each of three shape labels (i.e., the F, N and Q letters) with each of three color labels (i.e., D, J and X letters). Note that we used letters as labels because of their apparent discriminability (Vauclair and Fagot,