Abstract

We explored the psychological mechanisms of symbol manipulation by studying the constraints on spontaneous generalizations in human adults. We started from the hypothesis that the mind may use a set of specialized and constrained symbolic operations, some of which may derive from the constraints of the perceptual system.

We used Marcus et al.'s (1999) observation that young infants can generalize the structures ABA and ABB to ask whether such generalizations reflect general rule-extraction capacities or rather lower-level type-operations. In one series of experiments, we asked human adults to generalize repetition-based structures or 'ordinal' structures not entailing repetitions, both carried by piano tones. While general rule-extraction mechanisms should generalize both structures equally well, we showed that associationist mechanisms should process the *ordinal* structures better than the repetition-based structures. In contrast to both predictions, participants readily generalized repetition-based structures but performed poorly for the ordinal structures, and structure changes elicited rapid electrophysiological responses for the repetition-based structures but not for the ordinal structures. We concluded that repetition-based structures are processed by a specialized symbolic operation.

In the next series of experiments, we asked whether this operation was a general operator like in a computer or more constrained by perceptual factors. We found that participants could generalize repetition-based structures only when the repetitions were located in salient positions ; participants generalized the structure ABCDE*FF* but not the structure ABC*DD*EF. Control conditions ruled out that this advantage could be due to psychophysical difficulties. We concluded that the operation extracting repetitions-based structures may be highly sensitive to perceptual factors. Together, these results suggest that the generalization of repetition-based structures may not be diagnostic of general symbol-manipulating capacities, but rather of more specialized and constrained operations that strongly depend on the perceptual properties of the input ; we called such

operations 'perceptual primitives'.

We then asked whether lower-level operations like in the previous experiments might also underlie computations that are more related to language. We found that participants can learn some phonotactic constraints in word-edges but not in word-medial positions, and that the latter failure cannot be attributed to psychophysical difficulties. Nevertheless, participants could learn such constraints also in word-medial positions when the constraints entailed *natural* consonant classes rather than arbitrary ones, probably because this allowed participants to resort to similarity-based rather than symbolic computations.

In the next series of experiments, we asked whether category-based generalizations may also depend on perceptual factors. We first showed that human adults can extract category-based generalizations from a quasi-continuous speech stream in a situation inspired by the work of Peña et al. (2002) ; participants learned that syllables in the first and the last position of words had to be members of distinct classes. The preference for these generalizations was negatively correlated with the duration of the familiarization streams, which can be shown to be a signature of an associationist mechanism (computing for example TPs) competing with a rapid non-associationist mechanism computing the generalizations. We also showed, partly by simulations with artificial neural networks, that the generalizations could not have been computed by purely associationist mechanisms ; participants nevertheless performed statistical computations sensitive to second order TPs simultaneously with the non-associationist computations.

In the last series of experiments, we showed that such generalizations were available only when the crucial syllables were located in edge positions but not when they were located in medial positions ; statistical computations, in contrast, were possible also in medial positions.

Together, these results suggest that the mind may use a set of specialized and constrained operations, some of which may derive from the properties of the perceptual system ; such 'perceptual primitives' may act as a mental computational toolbox. Previous data as well as methodologi-

cal and evolutionary considerations suggest that such a piecemeal view of mental computations may be a prerequisite for studying the psychology of symbol manipulation and may contribute to a synthesis between symbolic and statistical models of the mind.