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Brief article

# Syntactic structure and artificial grammar learning: The learnability of embedded hierarchical structures

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**Abstract**

Embedded hierarchical structures, such as ''the rat the cat ate was brown'', constitute a core generative property of a natural language theory. Several recent studies have reported learning of hierarchical embeddings in artificial grammar learning (AGL) tasks, and described the functional specificity of Broca's area for processing such structures. In two experiments, we investigated whether alternative strategies can explain the learning success in these studies. We trained participants on hierarchical sequences, and found no evidence for the learning of hierarchical embeddings in test situations identical to those from other studies in the literature. Instead, participants appeared to solve the task by exploiting surface distinctions between legal and illegal sequences, and applying strategies such as counting or repetition detection. We suggest alternative interpretations for the observed activation of Broca's area, in terms of the application of calculation rules or of a differential role of working memory. We claim that the learnability of hierarchical embeddings in AGL tasks remains to be demonstrated.


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## 1. Introduction

A fundamental issue in language acquisition research concerns which rules children develop as a part of their grammatical knowledge and how these rules may be discovered (e.g., Chomsky, 1957; Reali & Christiansen, 2005). Artificial grammar learning (AGL) is a potentially valuable paradigm for determining processes of rule learning, both in terms of what structures are learnable (e.g., Fitch & Hauser, 2004; Gentner, Fenn, Margoliash, & Nusbaum, 2006; Newport, Hauser, Spaepen, & Aslin, 2004), and which properties of the language facilitate learning of these structures (e.g., Gomez & Gerken, 2000; Newport & Aslin, 2004; Onnis, Monaghan, Richmond, & Chater, 2005).

A natural language structure that has attracted interest in recent AGL studies is hierarchical centre embeddings (Fitch & Hauser, 2004, henceforth F&H; Friederici, Bahlmann, Heim, Schubotz, & Anwander, 2006; Gentner et al., 2006; Perruchet & Rey, 2005). In English, structures exemplified by *The rat [the cat ate] was brown* illustrate such centre embeddings, with additional embeddings possible, e.g., *The rat [the cat [the boy chased] ate] was brown.* Critically, these centre-embedded structures establish dependencies between constituents. Thus, such sentences have the structure $A_3A_2A_1B_1B_2B_3$, where the index values indicate the dependency between $A_i$- and $B_i$-elements. Such hierarchical embeddings are notoriously difficult to process in natural language (Bach, Brown, & Marslen-Wilson, 1986; Blaubergs & Braine, 1974; Foss & Cairns, 1970). Thus, demonstrating their learnability in AGL-experiments is a notable success.

Hierarchical embeddings have also been claimed to be of theoretical importance, as they require a context free grammar[1] to generate them and have been the focus of studies of human-unique structures in artificial language learning (Fitch, Hauser, & Chomsky, 2005; Hauser, Chomsky, & Fitch, 2002; Premack, 2004). In this respect they have been classified as different from the structures generated by finite-state grammars, for which local transitional dependencies can generate the sequence. F&H observed that humans could discriminate AAABBB-syllable sequences from ABABAB-syllable sequences (finite-state grammar), where A-syllables were spoken by a male human voice and B-syllables were spoken by a female. In contrast, cotton-top tamarins were insensitive to this distinction (though see Perruchet & Rey, 2005 for an explanation in terms of biological relevance, rather than structural dis-

[1] Context free grammars also enable hierarchically embedded patterns that do not entail dependencies among constituent elements, however the relevance of these patterns to human language is questionable. The studies by Fitch and Hauser (2004) and Gentner et al. (2006), for instance, focused on sequences without such dependencies. In this paper, however, we will focus on sequences that do entail dependencies.