Consciousness and Cognition 21 (2012) 1393–1400

Contents lists available at SciVerse ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

Implicit learning of conjunctive rule sets: An alternative to artificial grammars ☆

Greg J. Neil *, Philip A. Higham

Department of Psychology, University of Southampton, Highfield, Southampton SO17 1BJ, UK

ARTICLE INFO

Article history:
Received 12 March 2012
Available online 5 August 2012

Keywords:
Implicit learning
Subjective measures
Artificial grammar
Classification
Chunks

ABSTRACT

A single experiment is reported that investigated implicit learning using a conjunctive rule set applied to natural words. Participants memorized a training list consisting of words that were either rare-concrete and common-abstract or common-concrete and rare-abstract. At test, they were told of the rule set, but not told what it was. Instead, they were shown all four word types and asked to classify words as rule-consistent words or not. Participants classified the items above chance, but were unable to verbalize the rules, even when shown a list that included the categories that made up the conjunctive rule and asked to select them. Most participants identified familiarity as the reason for classifying the items as they did. An analysis of the materials demonstrated that conscious micro-rules (i.e., chunk knowledge) could not have driven performance. We propose that such materials offer an alternative to artificial grammar for studies of implicit learning.

1. Introduction

People can learn regularities in the world seemingly with no intention of doing so and without the ability to verbally describe those regularities, a phenomenon called implicit learning. By far the most common experimental paradigm used to investigate implicit learning is artificial grammar learning (AGL; e.g., Dienes & Scott, 2005; Higham, 1997a, 1997b; Reber, 1967, 1969; see Pothos, 2007 for a review). In typical AGL experiments, participants first observe or attempt to memorize a set of letter strings (e.g., MVXRT) that conform to an underlying rule set (finite-state grammar). After this training phase, participants are informed that all the strings they were just exposed to conformed to a rule set, but they are not informed about its nature. Instead, they are shown new strings during a testing phase that either conform to the rule set (grammatical strings) or not (nongrammatical strings) and asked to classify them accordingly. Many studies have shown that participants can make this discrimination at above-chance levels, but post-experimental interviews indicate that they are unable to verbalize the rule set used during training.

The mechanism(s) underlying AGL have been a subject of considerable debate. Reber (1967, 1969, 1989) has argued that learning occurs because participants abstract the underlying rule set and that this learning is not available to consciousness. Others have contested this assertion, suggesting instead that the learning that takes place is more superficial and/or more conscious in nature. For example, Johnstone and Shanks (2001) and Wright and Whittlesea (1998) argue that people do not distinguish grammatical from non-grammatical stimuli, but perform in ways that are consistent with the demands of the task. Where these demands happen to coincide with grammaticality, participants perform above chance, but without

☆ Portions of this research were presented at the Annual Meeting of the Psychonomic Society, 2009, Boston, MA. This research was supported in part by an ESRC studentship ES/F02200x/1 to the first author.

* Corresponding author.
E-mail address: G.Neil@soton.ac.uk (G.J. Neil).

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http://dx.doi.org/10.1016/j.concog.2012.07.005

unconsciously abstracting the underlying rule set. Dulany, Carlson, and Dewey (1984) argued that people learn simple conscious rules about permissible string fragments (*chunks;* e.g., bigrams or trigrams) within the strings. They demonstrated that although participants could not verbalize the complete rule set, they could identify those parts of the strings that made them grammatical. Furthermore, simulated rule sets from the underlined parts of the strings were enough to almost perfectly reconstruct participants' classification performance. Similarly, Perruchet and Pacteau (1990) argued that AGL is driven by conscious knowledge of sub-sequences of letters in the grammatical strings. They compared performance of a group of participants trained on typical strings used in AGL experiments with a group who only saw valid bigrams in training and found that test performance between the two groups was equivalent. Furthermore, items that were nongrammatical due to non-permissible bigrams were easier to reject than items that were nongrammatical due to permissible bigrams in the wrong place. Their conclusion was that learning was entirely due to conscious bigram knowledge.

Other researchers have also maintained that chunk knowledge is critical to AGL, but placed less emphasis on the acquired knowledge being conscious. For example, in Servan-Schreiber and Anderson's (1990) competitive chunking model, it is assumed that chunks are formed during training and are later used to judge test strings. Frequently occurring letter combinations allow for larger chunks to be formed, and if those larger chunks can be used to process test strings, larger familiarity values result. Because of the inherent structure of grammatical strings, larger chunks can be used to process them at test compared to nongrammatical strings, resulting in them having higher familiarity and more likely to be classified as grammatical. Other frameworks and models have been proposed to account for AGL that also fundamentally rely on superficial knowledge of chunks rather than rule abstraction (e.g., Dienes, Broadbent, & Berry, 1991; Jamieson & Mewhort, 2009a; Knowlton & Squire, 1994; Redington & Chater, 1996; although see Higham, 1997a).

1.1. Conjunctive rule sets as an alternative to artificial grammar stimuli

The nature of AG stimuli is such that regularities in the letter positions are hard to avoid, and so explanations of classification performance in AGL experiments often rely on, or must account for, chunks. Historically, chunking has figured highly in cognitive psychology, with demonstrations of its importance dating at least as far back as Miller's (1956) critical work on short-term memory and Chase and Simon's (1973) classic experiments with chess players. However, in the context of AGL, chunk knowledge, and in particular *conscious* chunk knowledge, is typically seen as a nuisance variable. In short, if conscious chunk knowledge can account for all learning in AGL experiments, as researchers such as Dulany et al. (1984) have proposed, then there actually may be nothing implicit about so-called "implicit learning". This has resulted in attempts to either control chunks or else obscure their presence. For example, Higham (1997a) controlled for chunks in AGL and demonstrated that above-chance performance still occurred and could be affected by factors that did not influence chunks, such as the pronouncibility of the strings. Norman, Price, and Jones (2011) obscured the nature of their artificial grammar strings by changing the font and color of the letters used across the test list, finding that even participants that claimed to be responding to these changes classified grammatical strings at above-chance accuracy. Other attempts to sidestep the issue of chunks have involved using non-local rules in music (Kuhn & Dienes, 2005) and even Tang poetry (Jiang et al., 2012). In our view, new materials and paradigms of this nature will enable us to further investigate the wide-ranging questions about human learning raised by AGL experiments whilst sidestepping issues related to the form of the stimuli.

In the current research, we abandoned AGL materials in favor of real English words incorporating a structure that is less likely to involve the influence of micro-rules. Higham and Brooks (1997; see also Higham, Bruno & Perfect, 2010) were the first to use a structure of this sort, so we will explain their methodology and results in some detail here. The training list of their second experiment consisted of natural words that conformed to the conjunction of two word categories. One category denoted the lexical frequency the words (i.e., rare versus common) and the other category denoted the grammatical class of the word (i.e., noun versus verb). Two training lists were constructed using these materials. The first list consisted of 50% rare-nouns (e.g., *hyacinth*) and 50% common-verbs (e.g., *destroy*), whereas the second consisted of 50% common-nouns (e.g., *carpet*) and 50% rare-verbs (e.g., *inculcate*). At test, participants either rated test items as consistent or inconsistent with the training list structure (classification) or as presented earlier in the training list or not (recognition). In both cases, test items were words representing all four conjunctions (i.e., common-nouns, common-verbs, rare-nouns and rare-verbs) and some had been presented earlier in the training phase (old words). For half the participants who were trained with the first training list, rare-nouns and common-verbs were consistent with the training-list structure, whereas rare-verbs and common-nouns were inconsistent. However, the opposite was true for the other half of participants trained on the second training list. For each training list, the data were collapsed across the two different consistent conjunctions and the two different inconsistent conjunctions to yield three stimulus types: old, new-consistent (NC) and new-inconsistent (NI).

Higham and Brooks (1997) found that participants were sensitive to the structure; that is, compared to NI words, NC words were given a higher *consistency* rating in classification and a higher *oldness* rating in recognition (i.e., higher false alarm rate), a difference they dubbed the *structural effect*. They also found that old words (which necessarily were consistent with the structure) were rated higher than NC stimuli, a difference they dubbed the *episodic effect*. However, not a single participant was able to verbalize the structure when asked about it in a post-experimental interview.

Higham and Brooks' (1997) design had a number of positive features for investigating implicit learning. First, because natural words were used instead of meaningless letter strings (as in typical AGL studies), the true nature of the training-list structure was made obscure (i.e., participants were "garden-pathed"). Indeed, the post-experimental questionnaire revealed