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# COMMENT

# Abstractness of Implicit Grammar Knowledge: Comments on Perruchet and Pacteau's Analysis of Synthetic Grammar Learning

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On the basis of 3 experiments, Perruchet and Pacteau (1990) argued that implicitly acquired knowledge of a synthetic grammar consists of little more than knowledge of pairwise associations between pairs of letters in the grammar. By comparing their results with a study by Mathews, Buss, Stanley, Blanchard-Fields, Cho, and Druhan (1989), it is argued that (a) implicitly acquired knowledge is much richer and more abstract than suggested by Perruchet and Pacteau, (b) their recognition measures are less sensitive than the Mathews, Buss, et al. recall measures for detecting conscious awareness of implicit knowledge, and (c) fragmentary knowledge of a grammar constitutes abstract rules that enable performance of complex tasks when integrated into a system for combining knowledge across rules.

Perruchet and Pacteau (1990) presented a bleak picture of implicit learning capabilities compared with other researchers who claimed that people can implicitly acquire abstract knowledge (e.g., Berry & Broadbent, 1988; Lewicki, 1986; Reber, 1989). Perruchet and Pacteau argued that exposure to strings generated by a grammar results in little more than knowledge of particular pairs of letters or bigrams that occur in the grammar. They reported three experiments. Experiment 1 showed that subjects who studied 20 valid strings generated by a grammar did not perform better on a subsequent string discrimination test than those who studied only pairs of letters that were valid bigrams in the grammar. Experiment 2 attempted to separate positional from associative knowledge about the grammar by testing subjects' ability to identify strings containing an invalid bigram (*NP* strings) versus a valid bigram in a wrong position (*NO* strings). The results of Experiment 2 indicated that there was above-chance recognition of *NO* invalid strings, but that the level of performance on these items was very low. Experiment 3 directly measured subjects' ability to identify bigrams, and included these data in a computer simulation in which bigram identification was used to successfully predict performance on the string discrimination task.

Their results contrast sharply with a recent series of artificial grammar experiments conducted in my lab (Mathews, Buss, et al., 1989). The Mathews, Buss, et al. study demonstrates that subjects implicitly acquire much more than bigram knowledge when exposed to a large quantity of exemplars generated by a finite state grammar. First I briefly describe the Mathews, Buss, et al. study and its results. Then, by comparing results of these two studies, I argue that the relative lack of knowledge of the grammar demonstrated by Perruchet and Pacteau's (1990) subjects can be attributed to three qualities of their experiments: (a) a relatively impoverished grammar in terms of positional information, (b) relatively low level of exposure to exemplars generated by the grammar, and (c) relative insensitivity of their recognition measures of conscious knowledge compared with the teach-aloud procedures used in Mathews, Buss, et al. Subsequently, I propose two definitions of abstract knowledge that avoid confusion associated with terms such as *formal rules* or *complex knowledge.* Finally, I argue that fragmentary knowledge of rules of a grammar are abstract, and that a nonconscious system that can integrate knowledge from sets of these rules is an extremely powerful mechanism for acquiring abstract knowledge.

## Richness of Implicit Knowledge in the Mathews, Buss, et al. (1989) Study

The results of the Mathews, Buss, et al. (1989) study demonstrate that subjects can implicitly acquire much more than just knowledge of legal bigrams when exposed to exemplars of a grammar. In that study, subjects were exposed to exemplars generated by a finite state grammar under implicit or explicit learning instructions. In the implicit conditions, subjects attempted to memorize strings. In the explicit conditions, subjects attempted to discover the rules of the grammar. A multiple-choice string discrimination task in which subjects attempted to discriminate valid strings from others containing incorrect letters was given either during training (Experiments 1 and 2) or after training (Experiments 3 and 4).

Mathews, Buss, et al. (1989) used a novel teach-aloud procedure for collecting verbal protocols concerning subjects' awareness of their implicit knowledge. This method involved

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interrupting the subjects periodically while they were working on the string discrimination task and asking them to give instructions to someone else about how to perform the task. The teach-aloud procedure has many advantages over prior attempts to have subjects verbalize their implicitly acquired knowledge of a grammar. The teach-aloud procedure assessed subjects' knowledge concurrent with performance of the string discrimination task rather than at the end of the experiment (see Ericsson & Simon, 1984). It also offered many retrieval opportunities per subject rather than one. Subjects verbalized instructions to perform the task after each block of 10 trials on the string discrimination task or a total of 20 times during a testing session. Typically only a few rules would be verbalized each time, but the entire set of rules verbalized by a subject gave a good account of their system of rules used to perform the task. This conclusion was verified by subsequent computer simulations in which the computer attempted to use the rules generated by subjects to perform the same string discrimination task. Performance of the individual subjects who generated the rules was found to be very similar to the computer's performance using their rules (Druhan & Mathews, 1989).

Knowledge of the grammar revealed by the teach-aloud procedure was rich and varied, and it contained much more than information about valid sequences of letters (bigrams, trigrams, and so on). It also contained a wealth of relative spatial information. Many verbalized rules indicated specific beginnings or endings of strings to select: "look for strings that begin with SCT or CVC" or "look for strings that end in VV or VPS." Subjects also frequently said to look for runs or repeated letters. Sometimes they set limits on length of runs or specified that the runs should occur in the middle of the strings. Finally, there often were "not" rules specifying certain types of strings to avoid. Subjects hardly ever mentioned a simple bigram or sequence of letters without specifying its general location in valid strings (e.g., beginning, middle, or end).

## Limitations of the Perruchet and Pacteau (1990) Study

Obviously, the results of the Mathews, Buss, et al. (1989) experiments were quite different from those of Perruchet and Pacteau (1990). These experiments cannot be compared directly because of the many methodological differences between them. However, it seems apparent that the richer knowledge in the verbal reports from the Mathews, Buss, et al. experiments can be traced to (a) a richer grammar in terms of length and relative positional stability of letters, (b) more extensive experience with exemplars of the grammar, and (c) greater sensitivity of the teach-aloud procedure compared with the recognition test used in Perruchet and Pacteau for measuring acquired spatial knowledge.

### *Differences in Grammars*

The grammar used by Perruchet and Pacteau (1990) is illustrated in the upper panel of Figure 1. It has six states, two loops, and two feed-backward arrows. The finite state grammar used by Mathews, Buss, et al. (1989) is illustrated in the lower panel of Figure 1. It has nine states, two loops, and three feed-backward arrows.

There are at least two major differences in strings generated by these grammars: (a) those generated by the Mathews, Buss, et al. (1989) grammar tend to be longer (mean length, 9.5 letters vs. 5.0 letters in the Perruchet and Pacteau, 1990, grammar), and (b) valid strings have less variable endings in the Mathews, Buss, et al. grammar. In the Perruchet and Pacteau grammar, any letter can occur in the final position. In the Mathews, Buss, et al. grammar, only two letters are permissible in the final position. Thus, endings in the Mathews, Buss, et al. grammar carry more information and can serve as better anchors for spatial information. Also, the longer length of Mathews, Buss, et al.'s strings made knowledge of relative spatial position more useful. For example, knowing that runs tend to occur near the end of strings could be valuable information in the Mathews, Buss, et al. grammar. Consequently, there is more opportunity to use spatial information in the Mathews, Buss, et al. grammar.

### *Differences in Practice*

In the Perruchet and Pacteau (1990) study, subjects studied a list of 20 exemplars of the grammar for 10 min. Although past research (e.g., Reber, 1976) has shown that this level of implicit training is effective for gaining some knowledge of the grammar, it is less likely to be sufficient to demonstrate the complexity of knowledge capable of being acquired through implicit learning. In the Mathews, Buss, et al. (1989) study, subjects studied 200 exemplars per week for a 3-week period.

### *Recognition Versus Recall Measures*

The fact that recognition performance is not always better than recall is a lesson learned earlier in the memory literature (see chapter 13 on recognition failure in Tulving, 1983). Verbal protocols and recognition tests are likely to reveal different knowledge, but we should be very careful about claiming that one technique is better or more sensitive than another (cf. Brody, 1989).

Recognition tests are not a panacea for studying conscious knowledge. Recognition tests only detect the specific information they were designed to find (e.g., spatial information), and then only when the available knowledge is adequate to discriminate between the choices on the test (e.g., whether a bigram is in its correct position or one or two positions off). On the other hand, open-ended (recall) techniques like teach aloud offer the opportunity to find knowledge the experimenter might not have anticipated. I wholeheartedly agree with Perruchet and Pacteau (1990) and Smolensky (1988) that it is unlikely that subjects' knowledge results from application of the very same rules as the ones used by the experimenter to conceptualize the task. However, more open-ended questions are more likely to elicit information about unanticipated types of knowledge that subjects may be using to perform the

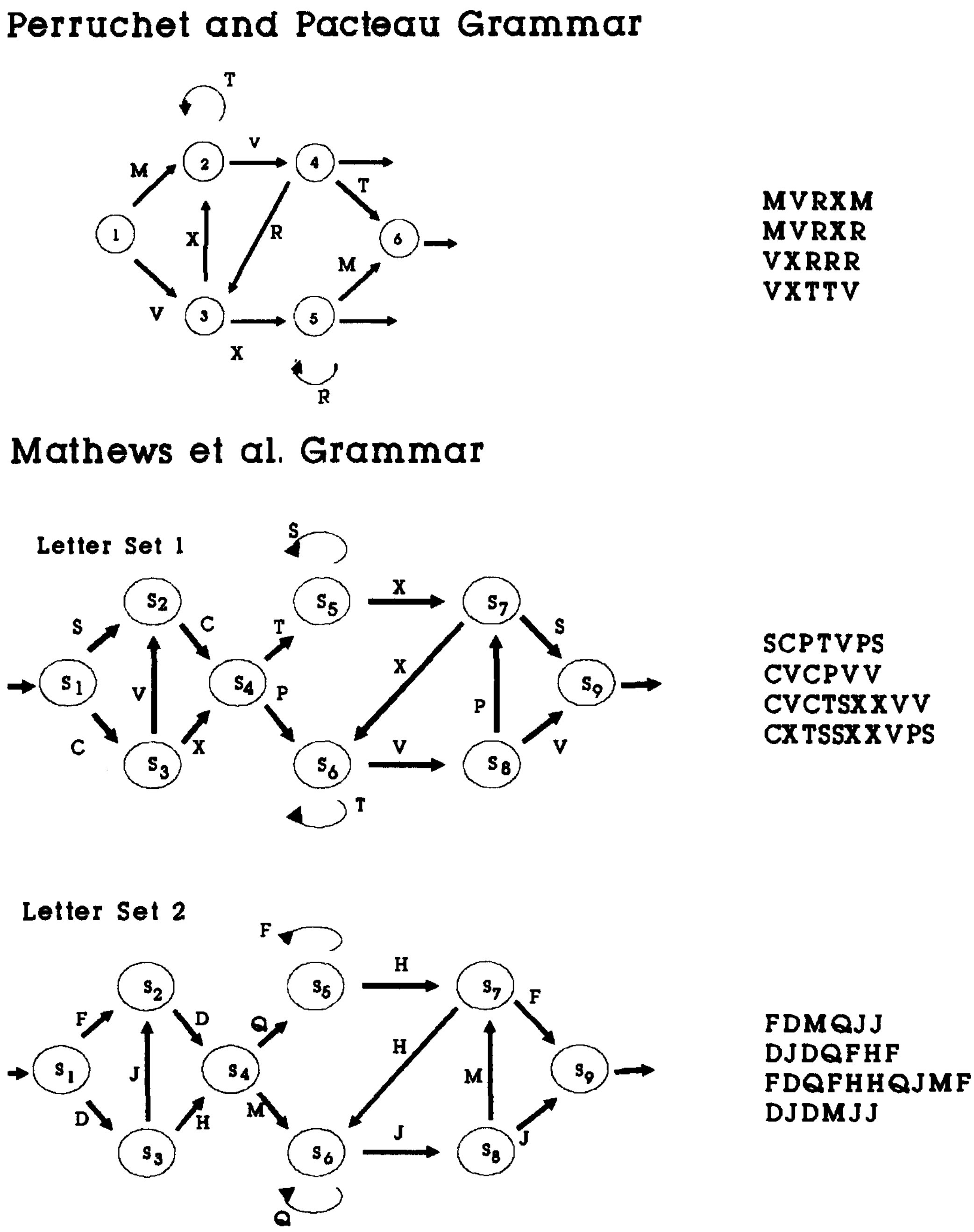


*Figure 1.* Grammars used in the Perruchet and Pacteau (1990) study and the Mathews, Buss, et al. (1989) study.

task than a recognition test designed to detect one type of knowledge.

The recognition test used by Perruchet and Pacteau (1990) required extremely accurate knowledge of spatial position of bigrams. The average length of the Perruchet and Pacteau strings was five letters. In testing for knowledge of spatial position in Experiment 2, they chose to ignore data from strings in which initial positions were violated. Further, final positions carry no information in this grammar because any letter can occur in that position. Thus, there were typically only three remaining positions used to examine recognition of spatial information. A bigram occupies two of the three positions. Thus, the range over which spatial information is violated in the invalid (NO) strings is only one or two positions away from its true location. The most amazing result of Perruchet and Pacteau's Experiment 2 is that, even under these extraordinarily difficult conditions (a grammar that generates short strings with relatively little positional stability, low level of experience with exemplars, and extremely difficult discrimination required for recognition test), they still found above-chance evidence for knowledge of spatial position of bigrams.

Another problem with the Perruchet and Pacteau (1990) data concerns their attempt to separate positional from associative (bigram) knowledge. A bigram inherently contains relative spatial information. The bigram AB means that A comes before B, and it is different from the bigram BA. Thus, knowledge about valid bigrams includes both associative information (A goes with B) and positional information (A precedes B). Subjects' implicit knowledge of artificial grammars, like their knowledge of real grammars, is rich with relative positional information. However, recognition tests that require absolute positional knowledge (exact positions a bigram should occur in) given after limited experience with a grammar (studying 20 examples) may not be sensitive enough to demonstrate that relative positional information was acquired.

## *The Nature of Abstract Knowledge*

In their study, Perruchet and Pacteau (1990) indicate that "the terms 'abstract' and 'complex' are loosely defined. However, in the present context, fragmentary knowledge of the pairs of consecutive letters included in the items may hardly be considered as abstract and complex." Earlier in their article, they also argued that connectionist models show that rule-dependent behavior may be mimicked by a cognitive architecture that never performs rule abstraction. Again, their point is that systems that can perform tasks that appear to require abstract rules can perform such tasks without abstracting the rules.

I propose two related definitions of abstractness of knowledge that avoid some of the confusion associated with the term *abstract* and allow one to determine the relative abstractness of knowledge. Under both of these definitions, fragmentary knowledge of letters in valid strings could qualify as abstract knowledge.

Research on genetic algorithms (see Goldberg, 1989), like other artificial-intelligence disciplines, tends to examine problems in terms of search spaces and possible alternative within such spaces. In grammar learning tasks, we might consider a space consisting of all possible combinations of allowable characters (e.g., the letter set used in the grammar) of a specified range of lengths as the search space. Each exemplar and nonexemplar of the grammar occupies one position in the search space. Rules for classifying strings identify one or more positions in the search space. Rules are more abstract to the extent that they identify a larger proportion of positions within the search space.

Therefore, a single exemplar is a maximally specific or nonabstract rule. A rule such as "select strings that begin with VXT" is more general or abstract because it identifies a larger number of positions in the search space. A rule such as "select strings that begin with V" is even more abstract. Rules that specify bigrams without specifying in what position they must occur are very abstract (and not very valid as a single rule).

The second method of defining abstract knowledge depends on performance in transfer tasks, and it is more closely related to the way Reber (1969, 1989) and others (e.g., Mathews, Buss, et al. 1989) examined abstractness of knowledge in artificial grammar experiments. For example, in the Mathews, Buss, et al. (1989) study, the letter set used to instantiate the grammar was changed in the second or third weeks of training (see Fig. 1). In this situation, knowledge is said to be abstract if it generalizes from the old search space to the new one, that is, if it carves out a section of the new search space with above-chance validity for identifying valid strings. The rules are abstract in this sense because they work in multiple search spaces.

A transfer definition of abstractness of knowledge is consistent with theoretical positions that recognize that knowledge is differentially useful for performing different tasks, for example, transfer appropriate processing (Bransford, Franks, Morris, & Stein, 1979) and procedures of mind (Kolers & Roediger, 1984). A transfer test for abstractness of knowledge stresses the applicability of knowledge gained in one situation to other similar situations. Different aspects of knowledge may be used to perform different tasks, or the same knowledge might be used in different ways. Nonetheless, we say abstract knowledge was acquired when transfer to a relatively novel task is successful.

Perruchet and Pacteau (1990) did not examine transfer in their experiments. If their subjects' knowledge consisted almost entirely of pairwise associations, it would be utterly useless in a transfer task using the same grammar instantiated with an entirely different letter set. However, previous studies (Reber, 1969; Mathews, Buss, et al. 1989) suggested that positive transfer would occur on such a transfer task, implying that abstract knowledge of the grammar was acquired.

Mathews, Buss, et al. (1989) found that subjects were able to use some of their knowledge in the new search space created when letter set was changed. The kinds of abstract knowledge subjects acquired that enabled them to perform above chance on the transfer task was also revealed by the teach-aloud procedure. It included such things as knowing that only a few beginning and ending patterns are allowed and looking for runs in the middle of strings. Mathews, Buss, et al. concluded that some abstract knowledge of the grammar was acquired as well as some letter-set specific knowledge that did not transfer.

The upshot of this argument is that rules based on fragmentary knowledge of the grammar, such as valid bigrams or trigrams from valid strings, constitute a set of abstract but weak (low validity) rules. Additionally, human subjects' performance in grammaticality judgment tasks goes far beyond the level of performance that could be achieved by using any one rule alone. Therefore, subjects must have a system for combining knowledge across sets of partially valid rules.

A simple system for combining bigram knowledge was implicit in the simulation that Perruchet and Pacteau (1990) used in Experiment 3. In their simulation, strings were classified as valid when every bigram in the string was recognized by a rule. Although this system was satisfactory for explaining the Perruchet and Pacteau data, it would not work whenever performance depends only on patterns of correlated features rather than individual features (Estes, 1986).

I believe classifier systems proposed by Holland, Holyoak, Nisbett, and Thagard (1986) offer a much more general model of knowledge integration that is applicable to artificial grammar learning (Druhan & Mathews, 1989; Mathews, Buss, et al. 1989; Mathews, Druhan, & Roussel, 1989) as well as many other domains in cognitive science (see Holland et al., 1986). Such models clearly demonstrate how fragmentary knowledge of valid strings can be integrated nonconsciously to perform complex tasks. The study of implicit learning will determine what types of covariation in sets of episodes can be apprehended without conscious analysis of similarities across these experiences. One already knows that this ability extends far beyond detection of pairwise associations.

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