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Active and Passive Statistical Learning: Exploring the Role of Feedback in Artificial Grammar Learning and Language

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Abstract

Language is immersed in a rich and active environment. One general dimension of that environment, feedback, may contribute greatly to learning language structure. Artificial-grammar learning offers an experimental means of exploring different kinds of potential feedback. In this paper, two experiments sought to investigate the role of feedback in an artificial-grammar learning task designed to resemble some aspects of language acquisition. An artificial language composed of auditory nonsense syllables and an accompanying visual semantics were created. Participants faced the task of mapping a sample sentence to a visual semantic scene. Results indicated that feedback is highly useful, allows participants to reach a high level of competence in the language, and also helps the acquisition of detailed aspects of the artificial grammar. Implications for language acquisition are discussed, and future directions considered.

Introduction

That humans can learn without any direct feedback has been well established for decades. From basic information extraction in perceptual processes (Gibson & Gibson, 1955), to social facilitation of a choice task (Bandura & Mischel, 1965), it seems that learning can occur passively and observationally across multiple levels of cognitive complexity.

One particular area of research with similar findings has been that of implicit learning or artificial grammar learning (AGL; Reber, 1967), in which subjects become sensitive to the regularities of a simple artificial grammar through passive exposure to sample sentences. A considerable amount of this research has been directed towards uncovering the mechanisms of this learning (e.g., Reber, 1967; Reber & Lewis, 1977; Vokey & Brooks, 1992; Redington & Chater, 1996; Cleeremans, Destrebecqz, & Boyer, 1998; Pathos & Bailey, 2000).

Learning through passive exposure to these grammars, however, is usually defined as performance at above-chance levels. Therefore, to gain further insight into language acquisition, theoretical and empirical bridges are needed between what may be called *passive structural learning* in these cases and the natural world, in which a learner acquires a firm competence with sequential structures in a meaningful, interactive context (e.g., see Berry, 1991, for an investigation of action in learning a probabilistic system). In pursuit of this, some research has been guided by questions about the possible connections between this kind of learning and real-world tasks, in particular language acquisition (e.g., Saffran, Aslin & Newport, 1996; Christiansen & Ellefson, 2002; Lupyan, 2002; Saffran, 2003). AGL can be used for studying the kinds of structural regularities that children discover while learning language (Saffran, 2003). The goal of this work has mostly involved exploring learning under passive observational exposure. Indeed, these experiments have demonstrated the richness of statistical learning under such circumstances.

However, language acquisition does not take place in a social vacuum. Instead, children are acquiring their native language while interacting with both people and things in the environment (e.g., Snow, 1999; Chouinard & Clark, 2003; Moerk, 1992; and even before two-word production; see Tomasello, 2003, for a review). In this context, and others in the natural world, relevant sequential behavioral structure *has a function* or *serves a purpose*, socially or otherwise, and its acquisition is immersed in this interactive context. What kind of information in the environment, and possible mechanisms in the learner, can supplement passive exposure to sequential structure in order to obtain a competence over what is to be learned? This paper presents a first step toward identifying one such dimension of learning. By using an AGL procedure, we explore the role of one kind of feedback that may be present in language acquisition.

We first offer a brief summary and review of this source of feedback in language acquisition. The potential for exploring this dimension is then presented in two experiments, demonstrating how an interactive task can bring a learner to a strong level of competence. In addition, we demonstrate that detailed aspects of an artificial grammar can be acquired in the context of feedback. We end with a discussion of implications, especially in view of language acquisition, and future directions this research may take.

Feedback in Language and AGL

Although the child may not be told explicitly that a given utterance or word is incorrect (also referred to as the lack of "negative feedback"; Saxton, 1997), the child does get other types of evidence or feedback.[1] For example, a mother may

[1] For simplicity, we do not consider the difference between negative feedback and negative evidence, though the distinction is important and may be explored by the experimental means presented here. See Saxton, 1997, for further discussion.

ask her child to pick up a particular toy, say a little plastic pig, from among several other toys. When the child successfully picks up the right toy, the mother may emphatically repeat the name of the target object: *The pig! Yes, that's the pig*. Once the child chooses the right toy, the mother repeats the label (e.g., *the pig*) and thus provides positive feedback on the child's correct mapping of the linguistic label to the appropriate object. Although there is considerable and continuing debate on the cultural variability of such practices (see Lieven, 1994, for a review and discussion), it is nevertheless possible that feedback of this nature may be present and useful in language acquisition (e.g., see Peters and Boggs, 1986, for a discussion of interactional routines across cultures).

Here we take a first step toward assessing the potential usefulness of such feedback in an AGL task meant to model the learning of sequential structure and how it maps to the non-linguistic world – a task not unlike what the child faces.

It should be noted that the role of feedback in language acquisition is highly controversial (see, for example, Morgan, Bonamo & Travis, 1995; Valian, 1999; Moerk, 2000; Saxton, 1997, 2000). It has perhaps for this reason not been extensively investigated in AGL research, where the focus has been on training techniques that largely parallel the kind of passive input considered central during language acquisition. Nevertheless, the role of feedback is widely acknowledged in such areas as skill acquisition (Moerk, 1992), learning theory (Rescorla, 1968), and reinforcement-learning models (Sutton & Barto, 1998).

There are therefore two primary objectives of the following experiments. A basic empirical objective is to consider the influence of feedback on AGL in a training procedure that resembles a natural-world context. To meet this goal, an experimental paradigm has been designed to resemble a kind of task faced by the child during language acquisition, adapted from Lupyan (2002; also, see Billman, 1989 and Morgan, Meier & Newport, 1987 for similar techniques).

Another objective is primarily theoretical: How does learning sequential structure get immersed in an interactive context and lead to competence? These experiments approach one aspect of an answer by considering how interactive feedback in a sequential learning task might bring the learner to a competent level of performance.

Experiment 1

This experiment is a first demonstration of the influence of feedback on learning an artificial grammar. The conditions in this experiment focus on the consistency of forms of feedback, and the extent to which the feedback is a salient, meaningful aspect of the learning task.

Method

Participants 51 college students were recruited for extra credit. Participation required approximately 20 minutes.

Materials A simple artificial grammar was created for the experiment, illustrated in Figure 1. Each category (e.g., N, *noun*) was instantiated by a set of nonsense syllables (e.g., *voop* or *jux;* see Table 1).

$$S \rightarrow N_1 \quad VP$$

$$VP \rightarrow \left\{ \begin{array}{l} \text{intransitive-V} \\ N_2 \quad \text{transitive-V} \\ N_2 \quad N_3 \quad \text{ditransitive-V} \end{array} \right\}$$

Figure 1: The artificial grammar

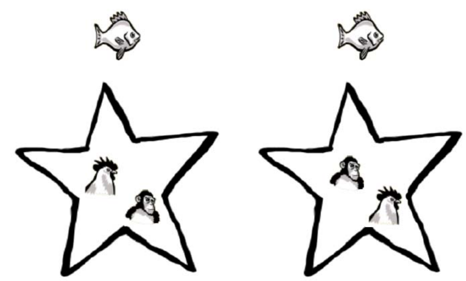

Figure 2: An example stimulus from one trial

An elementary visual "semantics" was created for this language. Each noun was randomly assigned an animal referent, and each verb had as its "meaning" a simple shape. Each nonsense syllable in the language had a referent of this kind in the visual semantics (Fig. 2).

Although the extent to which the visual scene contains a "subject" or "object" or "verb" is abstract, the language and its semantics are meant to capture structure-world correspondences not entirely unlike what might be seen in natural language structure.

Fifty random sentences were constructed for the experiment, and an incorrect visual semantic scene for each sentence was created (see Figs. 3 and 4). This incorrect scene was paired, as a foil, with the correct scene in training, as described below.

Table 1: Classes and assigned syllables

class	sounds	class	sounds
N	*kav*	Intran V	*voop*
	jux		*poox*
	ruj	Tran V	*sook*
	hep		*lem*
	pel	Ditran V	*rud*
	hes		*jove*

Procedure In every trial, participants saw two visual semantic scenes side by side then heard a sample sentence from the grammar. Their task was to select the appropriate visual semantics for the sentence heard. The task therefore involved learning the sequential structure of the grammar, and learning to map each sound to its semantic animal or shape.

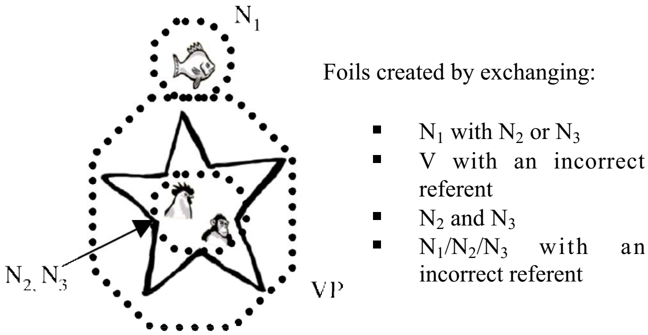

Figure 3: The structure of the visual scene and foils

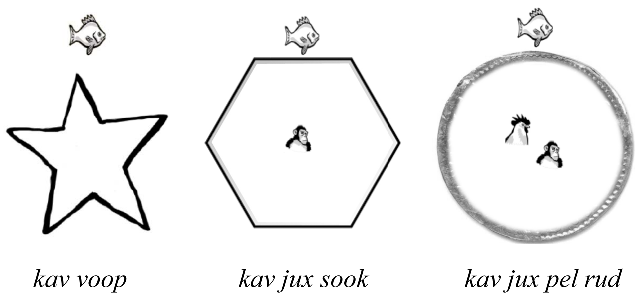

Figure 4: Example sentences

A *positive feedback event* was defined as a repetition of the sentence when the participants selected the appropriate visual semantic scene.

Two feedback conditions were investigated. Some subjects received *only* consistent feedback, occurring with 50% probability on any *correct* trial. Other subjects received 40% *random* repetitions, not contingent on the correctness of their selection (these probabilities were chosen so that all participants heard approximately the same number of repetitions).

Two further conditions were defined in terms of the kinds of instructions provided to subjects. In one condition, subjects were not informed about the meaningfulness of the repetitions (as positive feedback); in a second condition, subjects were explicitly informed that feedback would occur.

Out of the four possible subject groups, three were used in the experiment. One group received no instruction about the feedback but received it consistently. A second received no instruction, but the feedback occurred randomly. A third group of subjects received both consistent feedback and instructions about the presence of feedback during training.

Performance on the final 10 items of training served as the measure of learning. These items were new to the subjects. This permitted observation of performance in a continuous learning task without interruption. There was therefore no distinction between training and testing.

Results

No main effect for condition was found (corrected $F(2, 50) = 1.65$, $p = .21$). However, due to the probabilistic nature of the training phase, an additional planned regression analysis on each condition was conducted (because, by chance, some subjects may experience less consistent positive feedback than others). This was meant to investigate the number of actual feedback events experienced during the first 40 trials of training, and how it might predict performance on the final 10 items.

The only condition that produced a reliable predictive relationship was that in which subjects received information about the presence of feedback ($r = .65$, $p < .05$). Although the consistent feedback without instruction condition had a positive slope, the coefficient was not significant ($r = .28$, $p = .26$).

Discussion

This preliminary experiment offers some important observations. First, inconsistent feedback present in training did indeed stultify learning, even when the subjects were not certain about the significance of the sentence repetitions. We may tentatively contend that even contingent events in

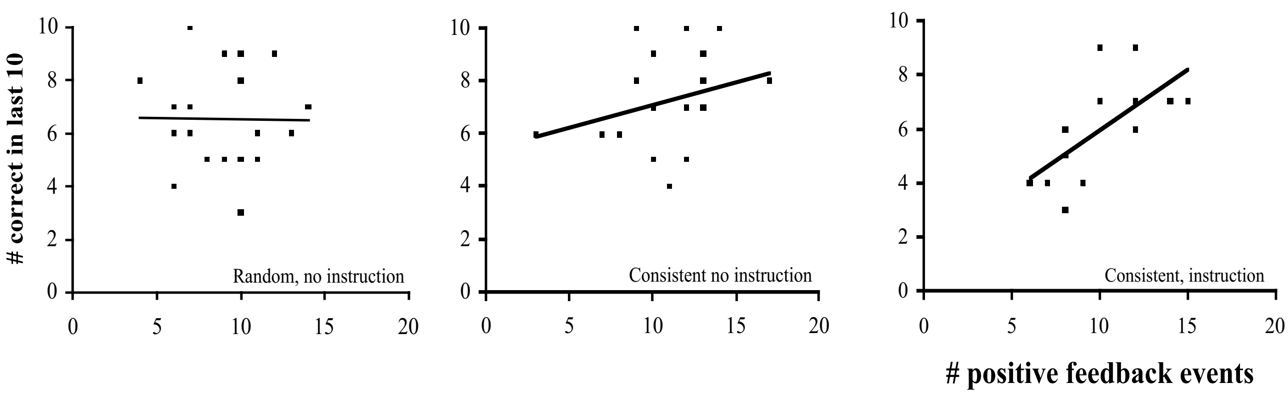

Figure 5: Regression analyses of different conditions. Each point represents a subject.

the learning environment can help or hinder learning sequential structure. It was *not* the case that learners simply ignored the repetitions and extracted the sequential invariants across the training trials.

Second, when participants were informed about the presence of feedback, the repetitions served as *significant* elements of acquiring the structure. It appears that subject performance became highly reliant upon even occasional, contingent repetitions of sentences as positive feedback, especially when the feedback was made meaningful to subjects. There is evidence that perceiving the import of such events may have an important influence on language acquisition (Saxton, 1997; Tomasello, 2003).

Despite these positive results, the learning that took place in the experiment hardly exhibits competence of the kind described in the introductory discussion. We therefore conducted a second experiment to address this and other questions. First, we enhanced the salience of the feedback event by changing the training environment. Second, we devised a separate test phase to explore the learning of specific kinds of structures in the grammar. Finally, we tracked learning of the grammar over time to observe the effect of feedback across training.

Experiment 2

Experiment 2 changed the nature of the feedback event to render it more salient. This involved not merely repeating the sentence, but also changing the visual environment selected by the participants. In addition, we explored how participants learned different aspects of the grammar, such as the abstract verb-argument structure.

Method

Participants 34 college-age participants were recruited for extra credit. Participation required approximately 20 minutes.

Materials The artificial grammar used was the same as in the first experiment. We created an additional 30 sentences to be used in a test phase without feedback. The paired incorrect visual scenes in these test items were constructed so as to sample across all possible grammatical errors. These included exchanging nominal shapes with an incorrect shape, inverting nominal shapes, and exchanging verbal shapes with incorrect shapes (see Fig. 3 for the kinds of foils used).

Once again, 50 sentences were presented randomly in a training phase. Feedback again was defined as a repetition of the spoken sentence.

Procedure Similarly to the first experiment, participants selected one of two visual scenes in response to a heard sentence of the grammar. This training once again consisted of 50 trials. Half the subjects received 60% feedback consistently, the other half hearing random feedback with 50% probability (these were selected once again so that all subjects heard approximately the same number of repetitions).

Given the results of the first experiment, it seems that salience of such feedback is a crucial property of using it in the task. To enhance this effect, we added a feature to the feedback event: When a correct visual scene was selected, the incorrect scene would be removed *and* the sentence would be repeated to the participant. This served to make these events as informative as possible to the participants. Also, this event may bear some resemblance to social interaction between the child and caregiver. When the child correctly interprets a lexical item, the caregiver may emphasize its referent object, thereby focusing the child's attention on it.

Following this training procedure, 30 trials were presented to participants *without* feedback in either condition. Performance on these 30 items served as the basic comparison between groups (consistent vs. random feedback), and item analyses allow us to investigate the role of feedback in acquiring more detailed aspects of the grammar (e.g., verb argument structure).

An additional control condition was conducted in which participants only experienced the test phase of the experiment.

Results

A main effect of condition (positive feedback, random feedback, control) was found ($F(2, 31) = 7.1$, $p < .01$). Subsequent comparisons among the groups indicated that only the positive feedback condition differed significantly from the random feedback and control groups ($p < .05$ in both cases; see Fig. 6). In fact, participants in the random feedback condition did not differ significantly from the control group ($p = .28$).

We further conducted item analyses within the positive and random feedback conditions to find wherein their performance differences lie (see Table 2). A repeated-measures ANOVA was conducted over the different kinds of items within subjects, and found that the primary differences in performance were in verb exchanges, the "subject" shape being exchanged, and a marginally significant result for identifying inversions in the argument structure of the verbal shapes.

By looking at the overall performance of participants, graphed over time, we get an interesting illustration of learning under the condition of consistent feedback (Fig. 7). The final 4 points include performance during the training stage.

Table 2: Number correct on different foils, and significance of the comparisons

Type of error in scene	Pos	Ran	Out of	p
Verbs different	5.2	3.8	6	< .05
Nouns different	3.8	3.8	5	.88
Sub exchanged w/ obj	12	8.8	14	< .01
Objects exchanged	3.2	2.4	5	.07

Discussion

These results further indicate that the salience of positive feedback in a sequential learning task of this kind can strongly influence performance. Participants in this task were performing almost perfectly in the positive feedback condition, even in the test phase, during which feedback was no longer issued.

Moreover, item analyses indicated that even subtle structure-world correspondences as the idealized "verb argument" structure in this artificial grammar was being learned more effectively under the condition of feedback.

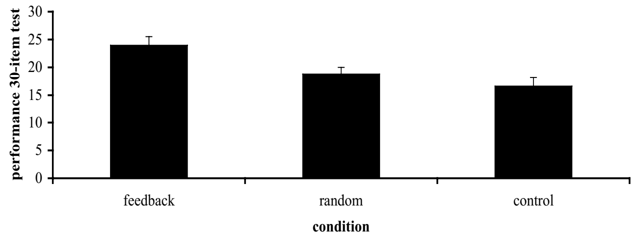

Figure 6: Performance by different groups

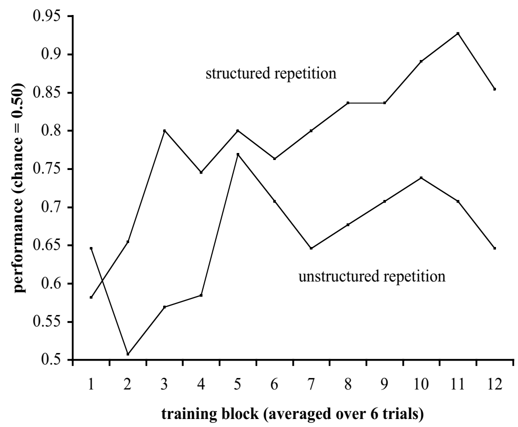

Figure 7: Performance over time averaged over trials

General Discussion

Although we feel the current experiments hold considerable promise, they do have limitations. First, although they more closely resemble natural-world contexts than previous research, they are still quite simple. Future experiments will address this issue by incorporating an even more interactive experimental task. Second, the grammar itself is quite simple, and *mere* passive exposure may be sufficient to learn it. Experiments are currently being conducted that directly compare passive exposure to scene-sentence pairs and the active selection task used here.

These limitations notwithstanding, the experiments have provided a first step towards investigating how feedback in an interactive task can bring performance in AGL to a more competent level than typically observed. The language acquisition literature itself has been deeply involved in debate for decades about the nature of feedback and evidence to children. For example, one may argue that the issue of positive and negative feedback has been resolved since Brown and Hanlon (1970), who demonstrated quite clearly that commonplace conceptions of feedback to a language learner are incorrect. Nevertheless, many continue to tease apart the negative and positive function of different types of input to children (e.g., Saxton, 1997; Saxton, 2000; Chouinard & Clark, 2003).

The experiments here can contribute to this endeavor. They may offer empirical means by which different kinds of feedback and their effects can be investigated experimentally, albeit here in college-aged subjects. The technique could be modified for children, and many of its dimensions explored in experiments with both children and adults. Some have pursued similar techniques such as "human simulations" (e.g., Gillette, Gleitman, Gleitman & Lederer 1999; Snedecker, Gleitman & Brent, 1999). For example, Snedecker et al. (1999) used college-aged subjects to explore the role of ambient social and environmental input to support a noun bias during language acquisition. This idea is not unlike what is being argued here (see Snedecker et al. for an interesting exploration and discussion of feedback in word learning).

More importantly, these experiments are intended to support a perspective in "ecological" sequential learning, and particularly language learning, that sees the task facing a learner as an active and interactive one. We would contend that such learning cannot *only* involve passively extracting statistical regularities from different modalities. Instead, sequential structure in the natural world, linguistic or otherwise, is *used* in an *interactive* environment – these uses generate consequences in the environment that impinge upon a learner's expectations and help carry the learner into a world of meaningful sequential structure.

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