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Authors
Hendricks, Michelle
Conway, Christopher
Kellogg, Ronald

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Dissociating Sources of Knowledge in Artificial Grammar Learning

Michelle A. Hendricks (mpatte20@slu.edu), Christopher M. Conway (cconway6@slu.edu), and Ronald T. Kellogg (rkellogg@slu.edu)
Department of Psychology, Saint Louis University
St. Louis, MO 63108 USA

Abstract

Previous studies have suggested that individuals use both implicit and explicit, as well as rule and exemplar-based knowledge, to make grammaticality judgments in artificial grammar learning (AGL) tasks. Experiment 1 explored the importance of explicit mechanisms in the learning of exemplar and rule-based information by using a dual-task during AGL training. We utilized a balanced chunk strength grammar, assuring an equal proportion of explicit exemplar-based cues (i.e. chunks) between grammatical and non-grammatical test items. Experiment 2 explored the importance of perceptual cues by changing letters between AGL training and test, while still incorporating the dual-task design and balanced chunk strength grammar used in Experiment 1. Results indicated that participants with a working memory load learned the grammar in Experiment 1 just as well as the single-task no-load group, presumably by relying solely on implicit learning mechanisms. However, changing the letters from training to test resulted in no significant learning for dual-task participants in Experiment 2, suggesting that exemplar-based perceptual cues may the major contributor to implicit knowledge. Overall, the results suggest that implicit and explicit mechanisms for learning rule-based and exemplar-based information may both contribute to AGL via four independent, parallel routes, providing a new framework for understanding the complex dynamic of learning in AGL tasks.

Keywords: artificial grammar learning; implicit learning; working memory; dual-task

Introduction

There is widespread agreement that there exist two distinct forms of learning, explicit and implicit. Explicit learning refers to learning that happens actively, consciously, and with effort, such as the type of learning that occurs during much of formal education. Implicit learning, on the other hand, occurs passively, unconsciously, and without effort. Implicit learning is theorized to be involved in procedural motor activities such as riding a bike or typing, as well as in more complex phenomena such as social interaction and language learning (Reber, 1993).

Artificial grammar learning (AGL) has been a useful paradigm for the study of implicit learning. In the typical artificial grammar learning (AGL) paradigm, individuals are shown (or asked to memorize) letter strings that, unknown to them, conform to rules instantiated by an artificial grammar. Following presentation of the training exemplars, participants are able to reliably determine whether a newly presented letter string is grammatical according to the artificial grammar, without being able to explicitly verbalize the rules of the grammar. Originally, it was theorized that individuals rely on an implicit abstract rule-learning system during AGL tasks, with participants' failures to verbalize the rules as evidence that the rules were unconscious (Reber, 1989).

Additional support for implicit rule-based learning in AGL was provided by what are now referred to as "transfer" experiments. In an AGL transfer experiment, the surface features (e.g. letters) of the training exemplars are changed during the test phase, though the underlying grammar stays the same. Clearly, this would make grammaticality decisions based solely on item similarity difficult, if not impossible. Thus, the transfer manipulation is meant to increase reliance on (presumably implicit) rules divorced from the surface details of the exemplars. Impressively, results from multiple studies have indicated that individuals still successfully demonstrate above-chance classification performance, though the learning is often attenuated (Reber, 1989, Knowlton & Squire, 1996).

In addition to the transfer studies, multiple studies have shown that amnesic subjects, who putatively cannot rely on explicit forms of learning, demonstrate artificial grammar learning similarly to non-brain damaged controls (Knowlton, Ramus, and Squire, 1992; (Knowlton & Squire, 1996). The evidence from both the transfer and the amnesic studies suggest that AGL is mediated by implicit rule-learning mechanisms. Under this view, given that implicit learning is theorized to happen automatically and without effort, executive functions such as working memory (an explicit mechanism, by definition) should have a minimal impact on artificial grammar learning.

Although studies with amnesic patients strongly suggest that AGL can occur without explicit memory, research with non-brain damaged subjects suggests that under normal conditions, explicit processes are also recruited. For instance, test phase classification judgments have been found to be sensitive to the similarity between test and training items, specifically in terms of chunk strength (Chang & Knowlton, 2004; Knowlton & Squire, 1996). Chunks are bigrams and trigrams that are encountered frequently in an artificial grammar due to repetitions in the underlying structure. Studies have shown that individuals do retain some explicit information regarding the chunks of the training items (Dienes, Broadbent, & Berry, 1991; Dulany, Carlson, & Dewey, 1984), and that participants studying only training bigrams can classify the grammaticality of test items correctly at rates similar to controls (Perruchet & Pacteau, 1990). In addition, fMRI studies of AGL tasks have suggested some involvement of the medial temporal lobe (MTL; Fletcher, Buchel, Josephs, Friston, & Dolan, 1999; Opitz & Friederici, 2004). These findings suggest that individuals may rely on a combination of both implicit rule-based knowledge and explicit exemplar-based chunk knowledge to make grammaticality judgments (Vokey & Brooks, 1992; Knowlton & Squire, 1996).

However, although it was originally assumed that rule knowledge is implicit and exemplar-based knowledge is explicit (e.g. Reber 1989), the true picture appears to be much more complex. For instance, participants in a study by Dulany, Carlson, and Dewey (1984) were able to indicate which parts of letter strings were grammatical by crossing out ungrammatical portions, possibly suggesting some explicit knowledge of rules. Similarly, participants in another study demonstrated explicit knowledge of the grammar by being able to complete stems of letter strings to form grammatical strings (Dienes, Broadbent, & Berry, 1991).

Similarly, it appears that implicit learning can also be used to learn both types of information (rule-based and exemplar-based). For instance, Knowlton and Squire (1996) used a balanced chunk strength grammar to show that amnesic patients showed the same pattern of performance as controls, suggesting they were sensitive to both exemplar-based and rule-based information, despite not having explicit knowledge for either. Chang and Knowlton (2004) assessed the importance of low-level perceptual features in AGL performance. Using a balanced grammar, they conducted two experiments: one in which they used a concurrent articulatory suppression task during learning (designed to disrupt perceptual processing), and one where they changed the font and case of letters from acquisition to test. In both cases, participants exposed to the manipulation experienced a disruption in chunk sensitivity, suggesting that exemplar-based knowledge may be more implicit than commonly thought.

In summary, the existing evidence appears to suggest that depending on learning conditions, exemplar and rule-based knowledge may both be acquired implicitly or explicitly. We therefore hypothesized that there may exist at least four separate pathways to learning in AGL (see Figure 1). Exemplar information may be acquired explicitly through memory for chunks (Dienes et al. 1991), or implicitly via perceptual processing (Chang & Knowlton, 2004). Likewise, rule-based knowledge may be acquired via an implicit rule system (Reber, 1967) or via explicit knowledge of rules (Dulany et al. 1984).

The current study aimed to test this proposed four-pathway theory of AGL by attempting to behaviorally dissociate each source of knowledge available to participants. In each of two experiments, we attempted to neutralize one or more of the four hypothesized pathways to knowledge illustrated in Figure 1. In Experiment 1, we incorporated an explicit dual-task during AGL, designed to prevent participants from relying on either form of explicit learning during training (hypothesis generation and item memory), leaving available only implicit sources of knowledge (perceptual fluency and abstract rule-learning). If the four-pathway theory is correct, we should expect that even under this dual-task condition, participants will still demonstrate learning equivalent to single-task participants because they still have access to exemplar-based and rule-based information via implicit learning. In Experiment 2, we

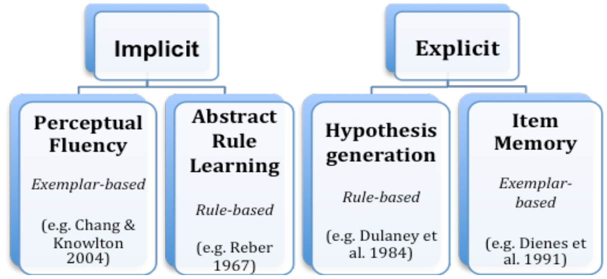

Figure 1: Hypothesized Pathways to Knowledge in Artificial Grammar Learning

furthermore neutralized the implicit perceptual fluency route to learning, leaving dual-task participants only with access to the hypothesized implicit rule-learning mechanism. Unlike Experiment 1, this manipulation is expected to drastically affect learning performance because only the (implicit) rule-based learning pathway is available. Finally, an additional aim of this study is to explore the relationship between individual differences in working memory ability and AGL performance.

Experiment 1: Dissociating Implicit from Explicit Learning

Experiment 1 was designed to address the question of whether learning in the AGL task can take place when explicit mechanisms, specifically working memory, are unavailable. To this end, half of the participants were engaged in a dual-task concurrently with the acquisition phase of the AGL task, designed to make explicit encoding of the stimuli during acquisition very difficult. The dual-task required participants to maintain a series of 6-digit strings in memory at the same time as they were exposed to the letter strings from the AGL task. For the AGL task, we used a balanced chunk strength design (Knowlton & Squire, 1996), which allows us to determine the relative contribution of learning processes to exemplar and rule-based knowledge. In a balanced chunk strength grammar, both grammatical and ungrammatical test items are balanced in terms of the chunks they have in common with the training items, thus ensuring that chunk learning alone cannot account for grammaticality performance. Since we have four categories of test items varying on two dimensions (chunk strength and grammatically), we are able to determine the impact of processing load from the dual-task on grammaticality and chunk strength separately.

We predicted that individuals with diminished explicit resources (i.e. via the concurrent working memory task during AGL acquisition) would still show learning (compared to a single-task control group) due to the availability of implicit mechanisms (perceptual fluency and abstract rule learning).

Finally, we also had each participant engage in an automated OSPAN task (Unsworth, Heitz, Schrock, & Engle, 2005) to measure their working memory abilities. This provided a way to assess the extent that working memory ability correlates with AGL performance in the dual- vs. single-task groups. We predicted that OSPAN task performance would be associated with AGL performance for the single-task group only, because unlike the dual-task group, their explicit learning pathways are available.

Method

Participants

Participants were 45 undergraduate students (23 in the single-task condition, and 22 in the dual-task condition) who participated for course credit.

Materials

Automated OSPAN The Turner and Engle (1989) OSPAN task requires individuals to solve math problems while trying to remember a set of unrelated words, and is a common measure of working memory. We used an automated version of the OSPAN, designed by Unsworth, Heitz, Schrock, and Engle (2005).The automated OSPAN (AOSPAN) correlates well with other measures of working memory capacity, demonstrating both good internal consistency and test-retest reliability (Unsworth et al. 2005).

Artificial Grammar The artificial grammar used in this experiment is from Knowlton and Squire (1996), which has the advantage of being a balanced chunk strength design (see Figure 2). To determine chunk strength, Knowlton and Squire (1996) quantified the similarity between learning and test items by determining the number of trigrams and bigrams in a test string that corresponded to those appearing in the learning items. We used the same 23 training items and 32 test items as did Knowlton and Squire (1996). The test items are divided into four chunk-balanced categories of 8 items each: grammatical low chunk (G-LC), non-grammatical low chunk (NG-LC), grammatical high chunk (G-HC), and non-grammatical high chunk (NG-HC).

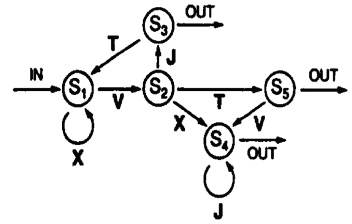

Figure 2: Balanced chunk strength grammar used in current study. From Knowlton and Squire (1996).

Procedure

Participants were assigned randomly to the dual-task or single-task condition, with all participants tested individually on a computer in a small, private room. All participants first completed the automated OPSAN task, followed by the AGL task. Participants in the dual-task condition completed a concurrent digit span task during the practice and acquisition phases, as described below.

Dual-Task Group After the automated OSPAN, the dual-task participants first received 3 blocks of practice trials to orient them to the task. Within each block, participants were presented with two or three sets of random letter strings consisting of the letters A, B, C, D, and E. For each string, participants were asked to type the letter string as shown in a space at the bottom of the screen; only after correctly typing the string were they allowed to proceed to the next trial. Participants were asked to use only one hand (their dominant hand) to type the strings. During these practice trials, the dual-task participants performed a concurrent working memory task. At the beginning of each practice block, participants were shown six random numbers presented in the middle of the computer screen for 3000ms. Participants were instructed to maintain the number string in their memory while typing the letter strings as described above. At the end of each block, participants then were required to type the six digits from memory.

Following the practice blocks, participants next completed the acquisition phase, which was nearly identical to the practice phase except for the following differences. Within each block, participants were presented with eight blocks of two or three letter strings each, where each letter string corresponded to one of the 23 training items from the artificial grammar[1]. Each training string was presented only once. As with the practice phase, participants were required to type the string correctly before advancing to the next trial, as well as maintain a 6-digit number string in memory, with a different number string given each block.

During the testing phase, participants were informed that the letter strings shown previously conformed to very complex rules, and that they should use their gut feeling to determine whether the letter strings presented next also conformed to these same underlying rules. Participants were then presented with the 32 test strings, and asked to decide whether each was grammatical or not by pressing a corresponding key on the keyboard. Immediately following each grammaticality judgment, participants were asked to rate their confidence regarding the judgment they had just made on a scale of 1-4 with 1 being “I am sure” and 4 being “I am guessing”.

Single-Task Group The single-task participants followed the exact same procedure as the dual-task participants, with the only difference being the nature of the concurrent task. The single-task participants saw a line of 6 asterisks instead of 6-digit number strings at the beginning of each AGL practice and acquisition block. They were not required to remember the asterisks during the trials; merely, at the end of each block, they saw each 6-digit number string and were asked to type it. In this way, the concurrent task did not tap working memory resources and thus serves as a good control to the dual-task group.

Results and Discussion

Main results are shown in Table 1. First we consider performance on the OSPAN and concurrent digit span tasks. As shown in the table, both groups performed comparably

[1] Training strings were randomized within blocks, and the blocks were presented randomly for every participant to account for any order effects.

on the OSPAN task, suggesting that the two groups possessed similar working memory abilities. The table also shows that for the concurrent digit span task, the dual-task participants correctly recalled all six digits at the end of each block 67% of the time (note that the single-task participants do not have a digit span score because they were not required to do the concurrent working memory digit span task). This score suggests that the dual-task had the desired effect of being challenging but not impossible to do. Furthermore, to act as a further control, a regression was conducted which indicated that the OSPAN score predicted 17% of the variance in digit span scores, which was marginally significant ($F(1, 20) = 4.13$, $p = .056$), implying that the effort expended on the dual-task was consistent with what would be expected given participants' working memory abilities. These results suggest that the dual-task had the desired effect of neutralizing or at the very least, attenuating, explicit processing resources for the dual-task group.

For the AGL task, Table 1 shows that both groups demonstrated learning as revealed by their test task performance being significantly greater than chance (single-task group, $t(22) = 5.30$ $p < .001$; dual-task group, $t(22) = 5.30$, $p < .001$). In fact, there were no significant differences between the single and dual-task participants on overall accuracy, the tendency to endorse items as grammatical, or classification confidence.

Even more strikingly, Figure 3 shows the test accuracy for each of the four categories of test items separately for each group. There were no differences between conditions on accuracy for each of the four categories. This indicates that both groups showed equivalent learning of the same two primary types of information present in the grammar (exemplar and rule-based information).

Interestingly, bivariate correlations indicated no correlation between accuracy and confidence judgments for either group. There was, however, significant positive correlation between the OSPAN score and accuracy in the single-task control condition ($r = 0.43$, $p < .05$), and a negative (but non-significant) correlation between the OSPAN score and accuracy in the dual-task condition ($r = -0.23$, ns). These results provide further support that our concurrent task did in fact neutralize working memory resources for the dual-task group; working memory positively contributed to control participants' ability to

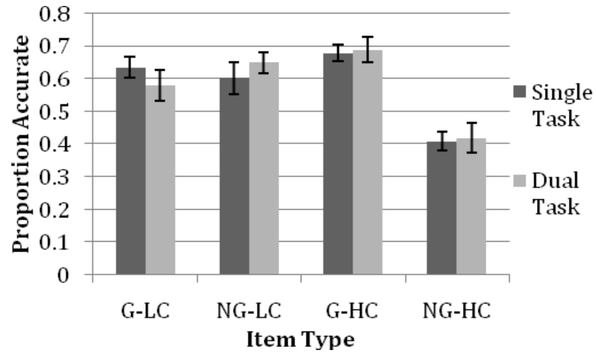

Figure 3: Proportion of Correct Grammaticality Judgments by Group and Item Type in Experiment 1.

correctly classify the grammaticality of test items, while it did not contribute to dual-task participants' ability to correctly classify test items. This suggests that the single-group participants were successfully using working memory to learn the grammar, while the dual-task participants were relying on a separate pathway to learning, as indicated by the lack of correlation of OSPAN scores with accuracy in the dual-task.

In sum, the results from Experiment 1 indicate that dual-task participants exhibited equivalent performance on the AGL task, despite having limited explicit resources available due to the concurrent working memory task during encoding. Strikingly, dual-task participants showed a pattern of learning indistinguishable from controls, indicating that explicit information is not necessary for the acquisition of either exemplar or rule-based information. Our results are consistent with the finding that patients with bilateral hippocampal brain damage (who are unable to explicitly encode information) also showed normal learning on an AGL task (Knowlton & Squire, 1996). Thus, one way to conceptualize Experiment 1 is that it provides a way to behaviorally "simulate" hippocampal brain damage using a concurrent working memory task. By forcing participants to engage in the concurrent digit span task, it appears we successfully prevented participants from relying on the explicit pathways to learning (item memory and hypothesis generation as shown in Figure 1); however, even without full explicit resources available for the AGL task, participants still were able to learn both exemplar and rule-based information in a presumably implicit fashion, leading to performance that was identical to the single-task group.

Table 1: Mean (Standard Deviation) Proportion of Correct Responses, Proportion of Items Endorsed Grammatical, Confidence, and OSPAN Score.

	Experiment 1		**Experiment 2**		
	Single-task	**Dual-task**	**Single-task**	**Dual-task**	**Control**
Proportion Correct*	.58 (.08)	.58 (.08)	.59 (.06)	.53 (.11)	.49 (.11)
Proportion Grammatical	.58 (.10)	.55 (.12)	.54 (.15)	.49 (.22)	.46 (.15)
Confidence	2.97 (.44)	2.68 (.64)	2.45 (.55)	2.62 (.79)	1.92 (.61)
OSPAN Score	47.64 (15.90)	44.77 (15.83)	44.30 (14.91)	48.38 (12.08)	44.12 (18.04)
Digit Span Score	NA	.67 (.19)	NA	.68 (.21)	NA

*Experiment 2: Between single-task and dual-task: $t(49)=2.51$, $p<.05$

Experiment 2: Dissociating Implicit Rule-Based from Exemplar-Based Learning

In Experiment 1, we forced the dual-task participants to rely on implicit learning to learn both exemplar and rule-based information. The aim of Experiment 2 was to attempt to remove an additional pathway to learning, namely implicit perceptual fluency, a form of exemplar based knowledge (see Figure 2), leaving only the implicit rule-based system hypothesized by Reber (1967).

In order to remove the availability of perceptual exemplar-based cues, we incorporated the "transfer" methodology described earlier. Specifically, participants were required to do the test classification task on test strings that consisted of an entirely new letter set. With no perceptual similarity between the acquisition and test phases, dual-task participants can only rely on a more abstract form of knowledge gained via the implicit abstract rule-learning route.

We therefore predicted that single-task participants would show some learning even without exemplar-based cues, since explicit rule-based sources of information would still be available. For dual-task participants, however, only the hypothesized implicit rule-based information will be available. Therefore, dual-task participants should still be able to make correct grammaticality judgments, but they may lose the sensitivity to chunk strength due to lack of exemplar-based cues. Alternatively, dual-task participants may fail to learn the grammar entirely if exemplar-based cues are crucial to learning, as suggested by some accounts (Johansson, 2009; Vokey & Higham, 2005).

Method

Participants

Participants were 84 undergraduate students (26 in the single-task condition, 25 in the dual-task condition, and 32 in the control condition) who participated for course credit. A non-trained control condition was used to ensure that any learning that takes place was not due to the test materials themselves.

Materials& Procedure

The materials and procedure for the single and dual-task groups were identical to Experiment 1, with the exception that the test strings used letters F, Z, N, and C in place of X, T, V and J, respectively. The replacement letters were chosen to be perceptually dissimilar from the training letters, and vowels were avoided so that words could not be formed from strings. Care was also taken to ensure that the letters used for test strings did not result in common acronyms that may interfere with the expression of learning.

The control group completed the same procedure as the dual and single-task conditions, with the exception that they were not given the AGL training. During test, they were told that the letter strings they were about to see were created using a complex set of rules, and that they should use their gut feeling to decide if each string belonged to the rules or not.

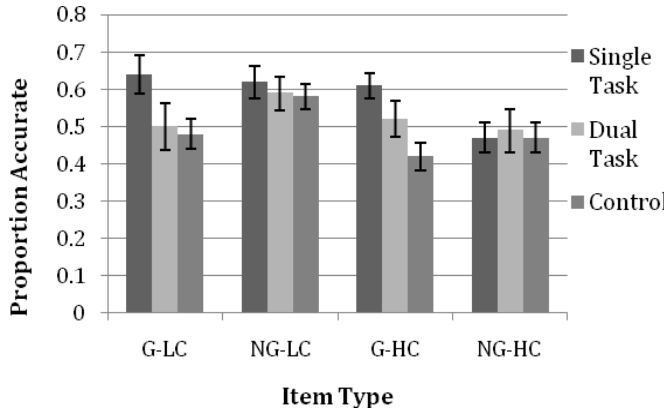

Figure 4: Proportion of Correct Grammaticality Judgments by Group and Item Type in Experiment 2

Results and Discussion

Again, we consider OSPAN and digit span scores first. As Table 1 shows, OSPAN results were equivalent between the two groups, suggesting that the groups' working memory abilities were evenly matched. In addition, performance on the dual-task (68%) was similar to Experiment 1.

As Table 1 also shows, accuracy on AGL test items was significantly greater than chance for the single-task participants only (59%, $t(25) = 6.86$, $p<.001$); dual-task test accuracy (53%, $t(22) = 1.08$, p = ns) and control accuracy (49%, $t(32) = -0.47$, p = ns) were not significantly greater than chance, indicating that only the single-task participants successfully learned the grammar. Further, single-task accuracy was significantly greater than dual-task accuracy ($t(49) = 2.51$, $p < .05$). As in Experiment 1, there were no significant differences between conditions on tendency to endorse grammaticality or classification confidence.

There were however significant differences between conditions on accuracy for the four categories of test items (See Figure 4). Though overall learning for dual-task participants was not significantly above chance, participants did show greater than chance accuracy for the NG-LC category of test items ($t(22) = 2.07$, $p < .05$). Nonetheless, control participants also demonstrated greater than chance accuracy on NG-LC items (t(22) =, df = 32, $p < .05$) suggesting that accurate performance on these items may reflect test item artifacts rather than implicit learning.

Bivariate correlations indicated no relationship between confidence, accuracy, and OSPAN scores for any group. This is in contrast to Experiment 1, in which there was a significant correlation between OSPAN scores and accuracy for single-task participants. It is unclear why this relationship would not persist in Experiment 2 given that access to explicit knowledge is presumably still available for single-task participants. It is possible that lack of perceptual information resulting from the transfer manipulation made explicit information regarding exemplars more difficult to utilize during grammaticality judgments at test.

Experiment 2 demonstrates that without explicit learning mechanisms and perceptual features, no learning takes place. We hypothesized that using a combination of concurrent dual-task and transfer methodology, the only pathway to learning left to participants would be the hypothesized implicit abstract rule-learning route. If true, then our results suggest that the kind of implicit rule-based learning originally hypothesized by Reber (1967) does not occur, at least not for transfer tasks. Instead, it appears that explicit mechanisms may be the sole source of knowledge in AGL transfer experiments (Redington & Chater, 1996).

General Discussion

The goal of this study was to attempt to dissociate implicit from explicit learning in artificial grammar learning by selectively neutralizing one or more of the four pathways that we hypothesized are available to learners. In Experiment 1, a concurrent dual-task was used during AGL acquisition to diminish explicit forms of learning. Participants in the dual-task showed strikingly similar test classification performance to the single-task control group, suggesting that they relied on a different – and presumably implicit – set of learning mechanisms at training to demonstrate the same learning as the single-task group. In Experiment 2, we added an additional manipulation – changing the letter set used in the test phase – in order to remove exemplar-based information. Without three of the four hypothesized learning routes, dual-task participants showed patterns of performance similar to non-trained controls, indicating that little to no learning occurred. Therefore, our results bring into question the idea of a rule-based implicit learning system proposed by Reber (1967). Instead, our results are more consistent with recent proposals that implicit knowledge is acquired primarily through exemplar-based perceptual mechanisms (Chang & Knowlton, 2004; Vokey & Higham, 2005). Alternatively, if an implicit rule-learning mechanism does exist, it does not appear to be recruited during AGL transfer tasks.

These results are consistent with the existence of independent implicit and explicit learning mechanisms operating in parallel. Interestingly, access to both implicit and explicit learning systems (e.g. single-task in Experiment 1) does not substantially enhance learning relative to when only implicit learning is available (dual-task in Experiment 1). This suggests that these systems do not operate synergistically. Future work investigating the development of these hypothesized pathways to knowledge in young children, as well as neuroimaging studies to specifically isolate the underlying neural circuits, may prove fruitful. Furthermore, we anticipate that this framework may have ramifications for understanding the nature of certain cognitive and neuropsychological disorders, especially cases in which cognitive learning mechanisms may be disturbed, such as dyslexia or other language impairments.

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