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# Role of selective attention in artificial grammar learning

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To investigate the role of selective attention in artificial grammar (AG) learning, participants were presented with "GLOCAL" strings—that is, chains of compound global and local letters. The global and local levels instantiated different grammars. The results of this experiment revealed that participants learned only the grammar for the level to which they attended. The participants were not even able to choose presented but unattended strings themselves. These results show that selective attention plays a critical role in AG learning.

In order to adapt to their environment, observers can incidentally learn covariations between variables when exposed to large amounts of information, even without being aware of their knowledge. Reber (1989) pioneered the investigation of such *implicit learning*, using artificial grammar (AG) learning (e.g., Reber, 1967). Since then, implicit learning has been studied using several paradigms—for example, most prominently, the serial reaction time (SRT) task, as well as AG learning (for reviews, see Dienes, 2008; Reber, 1989; Shanks, 2005).

In the learning phase of the AG learning procedure, participants are exposed to a series of letter strings that follow complex rules—typically, a Markovian rule system (e.g., Figure 1). In the test phase, they are asked to select grammatical strings from strings that violate the rules. Participants can correctly select novel grammatical strings above chance, even though they are unable to report the basis of their decisions; that is, their knowledge appears to be, on the face of it, implicit. Similarly, in the SRT procedure, participants' response latencies to events in patterned sequences become faster than those in random sequences, even when the participants say that they were unaware that there was a sequence (see, e.g., Cleeremans, Destrebecqz, & Boyer, 1998).

Implicit learning has been postulated to be an automatic consequence of selective attention (e.g., Perruchet & Vinter, 2002; Whittlesea & Dorken, 1993). Similarly, Reber (1989) suggested that some minimal amount of attention was needed for implicit learning to occur. On these accounts, some attentional selection must occur for implicit learning to occur. On the other hand, Lewicki (1986) thought that implicit learning could occur for unattended aspects of a task (see also, e.g., Jiang & Leung, 2005).

The role of selective attention has been investigated using the SRT task (e.g., Cock, Berry, & Buchner, 2002; Jiménez & Méndez, 1999; Rowland & Shanks, 2006). The evidence is largely consistent with Reber's claim that some minimal amount of attention to relevant task features is needed for implicit learning to occur. However, no study has investigated the role of selective attention in AG learning.

Seger (1998) argued that different mechanisms may underlie learning in the SRT task, which involves the acquisition of perceptual motor implicit knowledge, rather than learning AGs, which involves acquiring implicit knowledge for making judgments. Similarly, Boucher and Dienes (2003) speculated that sequential tasks such as SRT involve error correction mechanisms based on prediction, whereas AG may involve an automatic chunking mechanism. Plausibly, the roles of attention in learning may differ in SRT and AG learning. On the other hand, Perlman and Tzelgov (2006) suggested that associations can be automatically learned but that such knowledge would not be expressed in judgment tasks such as the grammaticality judgment used in AG learning. On such a view, AG learning will require a minimal level of attention, just as in the SRT task. This claim has yet to be tested.

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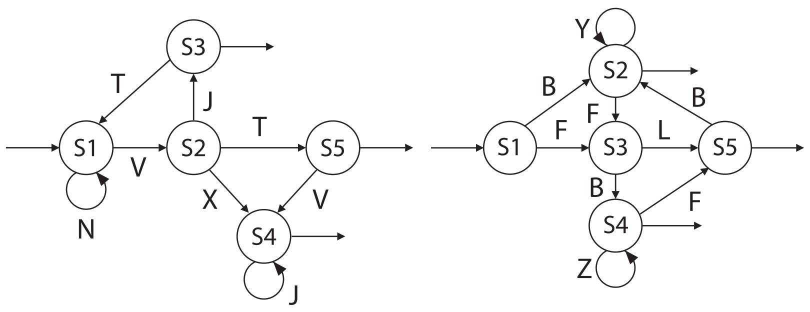


**Figure 1. Artificial grammars used in this study. The illustration on the left represents Grammar 1, and the one on the right Grammar 2.**

In order to manipulate selective attention in the AG learning procedure, we developed a new method using GLOCAL strings (see Figure 2). GLOCAL strings are chains of compound letters (Navon, 1977). Each compound letter represents one large letter (i.e., a global letter) that is composed of a set of small letters (i.e., local letters). When different letters are represented at the local and global levels for half a second or more, the two levels can mutually interfere with each other, indicating that attention to one level still allows processing of the to-be-ignored level (Hibi, Takeda, & Yagi, 2002). That is, there is automatic processing of the different levels of compound letters. Does such automatic registration of individual letters allow automatic chunking or other learning of letter sequences that are unattended? GLOCAL strings allow us to simultaneously present two different strings to investigate this question. For instance, a GLOCAL string can be read as one string using global letters (NVJTVJ in Figure 2), whereas it can also be read as another string using local letters (BYYFLB in Figure 2). Since GLOCAL strings can be made to follow two different AGs at the local and global levels, by manipulating participants' attention, we can examine whether they can learn the structure of the unattended strings. An advantage of this procedure is that we can manipulate attention merely by changing instructions, using the same procedure and objective stimuli, without any additional cognitive task or visual load.

The research question addressed by this article is whether or not selective attention is necessary for AG learning. If selective attention is needed in order to learn an AG through implicit learning, participants will learn the AG extracted from the attended level of GLOCAL strings, but not that from the unattended level. But if selective attention is not required for AG learning, participants will learn the structure of the strings even at the unattended level.

## EXPERIMENT 1

### Method

**Participants**. Forty undergraduates from the University of Tokyo participated in the experiment and received 500 yen following the completion of the experimental session. Assignments on global/local attention conditions and types of GLOCAL strings were counterbalanced.

**Stimuli**. Two different AGs were used; we used two structurally different AGs to avoid transfer of knowledge between the two different grammars. In a preliminary study, in which the same procedure had been followed as that in this study without the stimuli used in the learning phase, participants trained on one grammar could not accurately classify strings from the other [as compared with chance; $t(17) = 0.10$, 95% confidence interval (CI) = .497 ± .061]. Grammar 1 was that used in Knowlton and Squire (1996). Grammar 1 comprised five letters (J, N, T, V, and X) and Grammar 2 used the letters B, F, L, Y, and Z.

Eighteen grammatical strings with a length of three to six letters were constructed from each AG (see the Appendix). Two types of GLOCAL strings were constructed from the strings, following the two AGs. One type of GLOCAL string followed Grammar 1 at the global level and Grammar 2 at the local level, whereas this was reversed for the other type of GLOCAL string, so grammar was counterbalanced across levels.

GLOCAL strings were presented as white uppercase letters against a black background. Small letters were used in 12-point MS Gothic font. One large letter was the height of seven small letters. Eight small letters were arranged horizontally to obtain F, J, L, and X, nine to obtain B, N, T, and Y, thirteen to obtain V, and seven to obtain Z. The height of a large letter on the screen was approximately 3.2 cm, and the width was approximately 1.8–3.0 cm. The distance between the display and the participants was approximately 60 cm.

Twenty strings following each grammar used in the test phase were composed of five or six letters. These were not GLOCAL but regular letter strings. Half of these were used in the learning phase

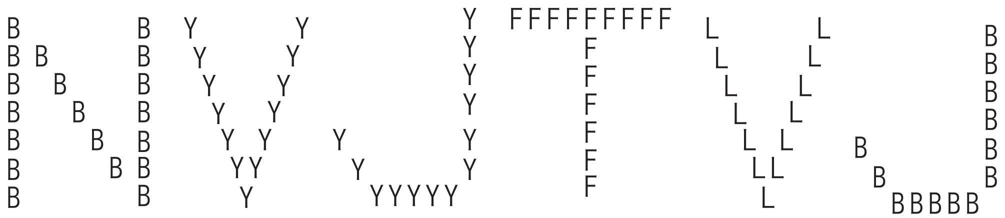

**Figure 2. The example of GLOCAL strings used in the learning phase.**

and will be referred to as *presented* grammatical strings. The remaining strings were not identical to any of the strings presented in the learning phase and will be referred to as *novel* grammatical strings. All these grammatical strings were used to construct nongrammatical strings that violated both of the grammars by placing one or two characters in nonpermissible locations.

Four types of string pairs were constructed for the test phase. The first type—*old–attended*—paired a presented grammatical string at the attended level of GLOCAL strings in the learning phase with a nongrammatical one based on the AG extracted from the attended level of the GLOCAL strings. The second type—*new–attended*—paired a novel grammatical string at the attended level of GLOCAL strings in the learning phase with a nongrammatical one based on the AG that was extracted from the attended level of the GLOCAL strings. Similarly, the third type was termed as *old–unattended*, and the fourth as *new–unattended*. Each type comprised 10 pairs. Thus, there were 40 pairs in the test phase. Matching pairs between grammatical and nongrammatical strings in each type were randomized for each participant, subject to the constraint that the two strings should have the same length.

**Procedure**. During the learning phase, 18 GLOCAL strings were presented on the display for 6 sec, during which the participants wrote down the string at their attended level, with each GLOCAL string presented six times. A mask stimulus comprising many "+" signs in the area where the GLOCAL strings were intended to be displayed was presented for the 1-sec interval between presentations of GLOCAL strings.

In the test phase, the participants were informed that two strings would be presented in the upper and lower regions of the display; each of the two levels of the training strings followed a set of rules; and each string of a pair followed one set of rules. The participants were required to press the key associated with the string that they judged to be grammatical. The 40 pairs were presented to each participant in a random order. A pair of strings remained on display until the participants pressed one of the two keys. The presentation of strings of a pair in the upper region was also randomized for each participant, subject to the constraint that one type of pair (i.e., the grammatical string) would be presented equally in each region. The 40 pairs were presented twice; in other words, the participants had to provide answers for 80 pairs.

**Design**. A 2 × 2 × 2 mixed design was employed. The first factor was global/local. The participants were instructed to attend to the global or local level in the learning phase. This was a between-participants factor. The second factor was attended/unattended. In the test phase, half of the pairs could be judged correctly on the basis of the grammar extracted from the attended level of the GLOCAL strings, whereas the other half could be judged correctly on the basis of the grammar extracted from the unattended level. This was a within-participants factor. In addition, the third factor, presentation—a within-participants factor—was whether or not the grammatical string had been presented before in the learning phase.

## Results and Discussion

Table 1 illustrates the mean classification accuracy for each condition in the test phase. First, the proportion of accurate classifications was subjected to a 2 × 2 × 2 mixed ANOVA with global/local, attended/unattended, and presentation (presented or novel grammatical string) as factors. The main effect of global/local was significant [$F(1,38) = 6.06$, $p = .018$, $\eta^2 = .040$]. Accuracy at the global level ($M = .63$) was higher than that at the local level ($M = .56$). The main effect of the attended/unattended level was also significant [$F(1,38) = 67.62$, $p < .001$, $\eta^2 = .280$]. Accuracy concerning the grammar of the attended level ($M = .69$) was higher than that of the unattended level ($M = .51$). The interaction between the global/local and attended/unattended levels was also significant [$F(1,38) = 9.31$, $p = .004$, $\eta^2 = .038$]. Simple effects revealed that accuracy in the global attention condition was higher than that in the local attention condition in the attended condition [$F(1,76) = 14.63$, $p < .001$], whereas this effect disappeared in the unattended condition ($F < 1$).

**Table 1**
**Mean Selection Rates for the Grammatical Strings in the Pairs of Old–Attended, New–Attended, Old–Unattended, and New–Unattended Grammatical Strings With Nongrammatical Strings in Experiment 1 (With Standard Errors)**

| | Types of Pairs | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Old–Attended | | New–Attended | | Old–Unattended | | New–Unattended | |
| Attended Level | *M* | *SE* | *M* | *SE* | *M* | *SE* | *M* | *SE* |
| Global | .770 | .026 | .733 | .034 | .500 | .031 | .518 | .029 |
| Local | .633 | .029 | .605 | .032 | .525 | .034 | .490 | .028 |

In order to examine the possibility that the participants could learn the AG from the unattended level to some degree, we compared the proportions accurately classified with chance (.5) in each condition. Accuracy for old–unattended and new–unattended in both global and local conditions was not higher than chance ($t$s $< 1$). Thus, the participants could not use the representations of the presented strings at the unattended level to extract AG knowledge (95% CI = .508±.033 in the unattended condition, overall).

The results of this experiment provide a strong test of the necessity of selective attention for learning AGs. Even when the very same strings as those presented at training at the unattended level were presented again at test, the participants could not classify them accurately.

# EXPERIMENT 2

The results of Experiment 1 showed that the unattended grammar was not learned at all. However, there is a possibility that the participants were not able to learn the unattended grammar because they did not even encode the information at that level (although contrast, e.g., Hibi et al., 2002; Navon, 1977). In Experiment 2, we examined whether the information at the unattended level was encoded by using a Stroop paradigm. If it takes more time to write down the GLOCAL string at the attended level when it is composed of different strings at the two levels than when it is composed of the same strings, there must have been encoding at the unattended level. On the other hand, if the information at the unattended level was not encoded at all, there would be no difference in the time taken to write down attended strings, depending on the identity of the unattended letters.

## Method

**Participants**. Thirty undergraduates from Chubu University participated in the control experiment and received a course credit following the completion of the experimental session.

**Stimuli**. The same two AGs as those in Experiment 1 were used. Twenty-eight grammatical strings with a length of six letters were constructed from each AG. Two types of GLOCAL strings were constructed from the strings, following two AGs. One type of GLOCAL string, newly made for this experiment, was composed of the same strings at both the global and the local levels, whereas the other type was composed of different strings, used in Experiment 1, each of which followed one of the two grammars. With regard to the latter, grammars were counterbalanced across levels.

**Design**. A 2 × 2 mixed design was used. The first factor was global/local. The participants were instructed to attend to the global or the local level. The second factor was congruent/incongruent. Both these factors were within-participants factors.

**Procedure**. The participants were asked to write down the strings at the attended level as quickly and correctly as possible and to press the space bar when they had done so. Each GLOCAL string was presented on the display until the space bar was pressed. After an interstimulus interval of 100 msec, the next string was presented. Twenty-eight stimuli were presented twice in a random order. The time to press the key from the onset of each string was measured. Each participant was tested twice, attending once at the global and once at the local level; the order was counterbalanced across participants.

### Results and Discussion

The mean reaction times (RTs) for writing the presented GLOCAL strings were subjected to a 2 × 2 ANOVA with congruent/incongruent (the global letter was congruent or incongruent with local letters in a GLOCAL string) and global/local (attended to the global or local level) as factors. The main effect of congruent/incongruent was significant [$F(1,29) = 42.89$, $p < .001$, $\eta^2 = .123$] indicating that the RTs for writing down congruent GLOCAL strings ($M = 5{,}200$ msec) were shorter than those for incongruent GLOCAL strings ($M = 5{,}592$ msec). The main effect of global/local was significant [$F(1,29) = 4.22$, $p < .05$, $\eta^2 = .094$], indicating that the RT for writing down the global level ($M = 5{,}225$ msec) was shorter than that for the local ($M = 5{,}568$ msec). The interaction between congruent/incongruent and global/local was also significant [$F(1,29) = 17.39$, $p < .001$, $\eta^2 = .002$]. Simple effects revealed that in the global attention condition, the RT in the congruent condition ($M = 5{,}107$ msec) was shorter than that in the incongruent condition ($M = 5{,}343$ msec) [$F(1,29) = 11.49$, $p < .01$]. In the case of the local attention condition, the RTs in the congruent condition ($M = 5{,}294$ msec) was also shorter than those in the incongruent condition ($M = 5{,}842$ msec) [$F(1,29) = 58.87$, $p < .01$]. These results were consistent with those in previous studies based on the usage of this kind of stimuli (e.g., Hibi et al., 2002; Navon, 1977), including the asymmetrical tendency between the global and the local levels. Importantly, the interference effect of incongruent versus congruent GLOCAL strings reveals encoding of the unattended aspect of GLOCAL strings under the conditions of our experiment.

## GENERAL DISCUSSION

The results indicate that selective attention plays a critical role in AG learning. More specifically, the participants could learn an AG only from the attended level of the GLOCAL strings. The participants looked at the letters at the unattended level for over 10 min in the learning phase. Attentive looking for 10 min has previously been shown to be sufficient for substantial AG learning, at least above 60% (e.g., Dienes, Broadbent, & Berry, 1991; Dulany, Carlson, & Dewey, 1984; see also Reber & Allen, 1978). Here, we show that such looking should, indeed, be attentive for implicit learning of AGs to occur (see also Eitam, Schul, & Hassin, 2008). We can conclude (with a tight confidence interval) that there was no learning of the unattended strings. Indeed, in a separate experiment with different stimuli, we replicated accurate classification of stimuli from the attended grammar [$t(35) = 5.47$, $p < .001$; 95% CI = .622±.045] but no detectable learning of stimuli from the unattended grammar (95% CI = .494±.043). Such sensitivity to selective attention means that implicit learning as revealed in AG learning behaves in much the same way as in the SRT task and supports the notion that there is a single set of principles that underlie implicit learning in all domains (but see Kuhn & Dienes, 2005, for the argument that the content of what is learned may vary across domains, even if many processing principles are the same).

A more nuanced conclusion follows from Lavie's (e.g., 2005) argument that the amount of perceptual processing of nominally unattended items depends on the overall perceptual load. According to Lavie, when the perceptual processing load of the target domain is high, unattended stimuli are not processed deeply; conversely, when target perceptual load is low, unattended stimuli are processed more deeply. Consistently, Rowland and Shanks (2006) found that learning of a distractor sequence in the SRT task could occur, but only for a low, rather than a high, perceptual load on the target task. A minimum amount of perceptual processing appears to be necessary for implicit learning. Perhaps, in a simple environment, unattended stimuli or aspects of stimuli may be sufficiently processed to allow learning (cf. Mayr, 1996), although this remains to be shown for AG learning. In a rich natural environment—that is, one in which there is a high perceptual load—achieving the minimum amount of perceptual processing for implicit learning to occur requires selectively attending to relevant stimuli and features, as we have shown. If current results are consistent with an important role for attention at the perceptual level, they leave open the importance of attention conceived of as cognitive control processes (Lavie, 2005)—that is, the resources disrupted by such tasks as random number generation (RNG). Dienes et al. (1991) showed that RNG interfered with AG learning, although Dienes, Altmann, Kwan, and Goode (1995) and Dienes and Scott (2005) have argued that such interference occurred only when there was conscious knowledge of the structure of the strings. This claim, that the acquisition and application of unconscious structural knowledge occurs independently of central resources (Dienes, 2008), needs more general testing.

The results of this experiment suggested that there is a global/local asymmetry in AG learning using GLOCAL strings. More specifically, classification accuracy in the global attention condition was higher than that in the local attention condition. This finding is consistent with the claim for a general preference for processing at the global level (see Navon, 2003, for a review), although we hope to explore individual and cultural differences in this preference as it affects implicit learning (cf. Nisbett, 2003).

Thus, implicit learning reflects not simply the abstract structural properties of stimuli (i.e., the stimuli simply as a string of letters), but also the exact visual form of the stimuli (contrast Pothos & Bailey, 2000).

In sum, we argue that selective attention plays a vital role in the implicit learning of AGs. In terms of computational models of implicit learning (Cleeremans & Dienes, 2008), features must be at least minimally attended to have encodings strong enough to allow networks to transform the input—and learn transformations of the input—in all the ways that make possible our implicit mastery of the rich natural environment.

## AUTHOR NOTE

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## REFERENCES

Boucher, L., & Dienes, Z. (2003). Two ways of learning associations. *Cognitive Science*, **27**, 807-842.

Cleeremans, A., Destrebecqz, A., & Boyer, M. (1998). Implicit learning: News from the front. *Trends in Cognitive Sciences*, **2**, 406-416.

Cleeremans, A., & Dienes, Z. (2008). Computational models of implicit learning. In R. Sun (Ed.), *Cambridge handbook of computational psychology* (pp. 396-421). Cambridge: Cambridge University Press.

Cock, J. J., Berry, D. C., & Buchner, A. (2002). Negative priming and sequence learning. *European Journal of Cognitive Psychology*, **14**, 27-48.

Dienes, Z. (2008). Subjective measures of unconscious knowledge. In R. Banerjee & B. Chakrabarti (Eds.), *Models of brain and mind: Physical, computational and psychological approaches* (pp. 49-64). Amsterdam: Elsevier.

Dienes, Z., Altmann, G. T. M., Kwan, L., & Goode, A. (1995). Unconscious knowledge of artificial grammars is applied strategically. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **21**, 1322-1338.

Dienes, Z., Broadbent, D., & Berry, D. (1991). Implicit and explicit knowledge bases in artificial grammar learning. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **17**, 875-887.

Dienes, Z., & Scott, R. (2005). Measuring unconscious knowledge: Distinguishing structural knowledge and judgment knowledge. *Psychological Research*, **69**, 338-351.

Dulany, D. E., Carlson, R. A., & Dewey, G. I. (1984). A case of syntactical learning and judgment: How conscious and how abstract? *Journal of Experimental Psychology: General*, **113**, 541-555.

Eitam, B., Schul, Y., & Hassin, R. R. (2008). *Goal relevance and artificial grammar learning*. Manuscript submitted for publication.

Hibi, Y., Takeda, Y., & Yagi, A. (2002). Global interference: The effect of exposure duration that is substituted for spatial frequency. *Perception*, **31**, 341-348.

Jiang, Y., & Leung, A. W. (2005). Implicit learning of ignored visual context. *Psychonomic Bulletin & Review*, **12**, 100-106.

Jiménez, L., & Méndez, C. (1999). Which attention is needed for implicit sequence learning? *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **25**, 236-259.

Knowlton, B. J., & Squire, L. R. (1996). Artificial grammar learning depends on implicit acquisition of both abstract and exemplar-specific information. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **22**, 169-181.

Kuhn, G., & Dienes, Z. (2005). Implicit learning of nonlocal musical rules: Implicitly learning more than chunks. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **31**, 1417-1432.

Lavie, N. (2005). Distracted and confused? Selective attention under load. *Trends in Cognitive Sciences*, **9**, 75-82.

Lewicki, P. (1986). *Nonconscious social information processing*. New York: Academic Press.

Mayr, U. (1996). Spatial attention and implicit sequence learning: Evidence for independent learning of spatial and nonspatial sequences. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **22**, 350-364.

Navon, D. (1977). Forest before trees: The precedence of global features in visual perception. *Cognitive Psychology*, **9**, 353-383.

Navon, D. (2003). What does a compound letter tell the psychologist's mind? *Acta Psychologica*, **114**, 273-309.

Nisbett, R. E. (2003). *The geography of thought: How Asians and Westerners think differently*. New York: Free Press.

Perlman, A., & Tzelgov, J. (2006). Interactions between encoding and retrieval in the domain of sequence-learning. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **32**, 118-130.

Perruchet, P., & Vinter, A. (2002). The self-organising consciousness: A framework for implicit learning. In R. M. French & A. Cleeremans (Eds.), *Implicit learning and consciousness: An empirical, philosophical and computational consensus in the making* (pp. 41-67). Hove, U.K.: Psychology Press.

Pothos, E. M., & Bailey, T. M. (2000). The role of similarity in artificial grammar learning. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **26**, 847-862.

Reber, A. S. (1967). Implicit learning of artificial grammars. *Journal of Verbal Learning & Verbal Behavior*, **6**, 855-863.

Reber, A. S. (1989). Implicit learning and tacit knowledge. *Journal of Experimental Psychology: General*, **118**, 219-235.

Reber, A. S., & Allen, R. (1978). Analogic and abstraction strategies in synthetic grammar learning: A functionalist interpretation. *Cognition*, **6**, 189-221.

Rowland, L. A., & Shanks, D. R. (2006). Attention modulates the learning of multiple contingencies. *Psychonomic Bulletin & Review*, **13**, 643-648.

Seger, C. A. (1998). Independent judgment-linked and motor-linked forms of artificial grammar learning. *Consciousness & Cognition*, **7**, 259-284.

Shanks, D. R. (2005). Implicit learning. In K. Lamberts & R. L. Goldstone (Eds.), *Handbook of cognition* (pp. 202-220). London: Sage.

Whittlesea, B. W. A., & Dorken, M. D. (1993). Incidentally, things in general are particularly determined: An episodic-processing account of implicit learning. *Journal of Experimental Psychology: General*, **122**, 227-248.

## APPENDIX

**Table A1**
**Strings Used in the Learning Phase of Experiment 1**

| Grammar 1 | | | Grammar 2 | | |
|---|---|---|---|---|---|
| NVJTVJ | VJTVTV | NVJTVX | BYYFLB | BYFLBY | BYFBZZ |
| VJTNVX | NNVXJJ | NVTVJJ | BFLBYY | FLBFLB | FLBFBF |
| VTVJJJ | VJTVJ | NNNVT | FBZZFB | BYYFL | BYFLB |
| NNVTV | NVTVJ | VTVJJ | BFBZZ | FLBYY | FBZZZ |
| VXJJJ | NNVT | VTVJ | FBZFB | BYFB | BFBZ |
| NVXJ | VTV | VXJ | FBZZ | BFL | FBF |

**Table A2**
**Strings Used in the Test Phase of Experiment 1**

| Grammar 1 | | | | Grammar 2 | | | |
|---|---|---|---|---|---|---|---|
| Grammatical | | Nongrammatical | | Grammatical | | Nongrammatical | |
| Presented | | | | | | | |
| VJTVTV | NVJTVX | JJTVTV | NVXTVJ | BYFLBY | BYFBZZ | ZYFLBZ | BYFZZL |
| VJTNVX | NVTVJJ | XJTTVX | NVXVJT | BFLBYY | FLBFBF | BFZZYY | LLBFBF |
| VTVJJJ | NNNVT | VTVJTN | TNNVT | FBZZFB | BYFLB | FBYYFB | BZFLB |
| NNVTV | NVTVJ | NNVJJ | TVTXJ | BFBZZ | FLBYY | BFBYY | FLLZY |
| VTVJJ | VXJJJ | VTVTN | VXTXJ | FBZZZ | FBZFB | FBZFZ | FLZFB |
| Novel | | | | | | | |
| VJTNVJ | VJTNVT | VXTTVJ | XJTTVT | BYYYFB | BYYFBZ | ZYYYFL | BYYFZL |
| NNNVTV | VJTVXJ | TNNVTX | VJJTXJ | BFLBFL | FLBYFL | BFLZFZ | ZLBYFZ |
| NVXJJJ | NNNVJ | NVXJTT | TTNVJ | FBZZZF | BYYFB | FLZZYF | BZYFZ |
| VJTVT | VJTVX | VJJTT | VJTXV | BYFBF | BFLBY | BYFZL | BZLZY |
| NNNVX | NNVXJ | XTNVX | TNVXV | FLBFB | FBFBY | FLZFB | FZLBY |

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