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Abstract

Previous research using the chain of compound letters as letter strings in artificial grammar learning (AGL) suggested that visual saliency known as global precedence influenced the extent of learning. In this study the luminance of letter strings in the learning phase was manipulated to investigate the effect of visual input on AGL regardless of top down attention control. As a result, participants assigned to the low luminance condition were not able to learn any grammar even though they could percept letter strings in the learning phase. This finding suggested that AGL is influenced by the visual saliency from outer environment independently of top down attention control. The results implied that AGL mechanism as adaptive system is affected both by the top down selective attention to acquire covariance sensitively and by the bottom up visual saliency from the complex environment rather than automatic processing system.

Keywords: Implicit learning; artificial grammar learning; selective attention

Background

Implicit learning is a generic term used to refer to the phenomena that observers can implicitly identify the covariation between some variables when exposed to large amounts of information in order to adapt to their environment (Reber, 1989). Artificial grammar learning (AGL) is known as the one of the most popular experimental procedures in the realm of implicit learning research. The typical procedure of the AGL experiment comprises two phases. In the initial phase of the AGL procedure, i.e., the learning phase, participants are exposed to a series of letter strings that follow complex rules, typically a finite-state Markovian rule system (Figure 1).

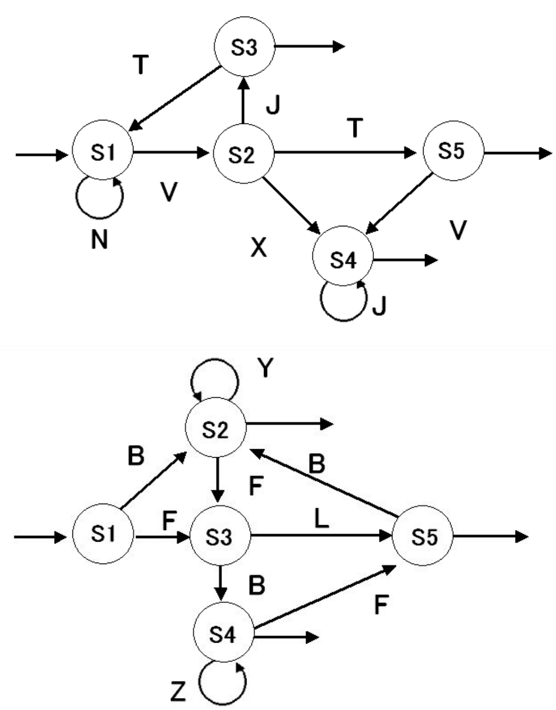

Figure 1: Artificial grammars used in this study. The illustration on the top of the panel represents Grammar 1, and Grammar 2 on the bottom. These can generate "grammatical" letter strings connecting letters from state 1(S1) to outputs through some states (for example, grammatical NVJTVT was generated from Grammar 1, S1-S2-S3-S1-S2-S5). Grammar 1 was the same as that used in Knowlton and Squire (1996), in terms of the abstract structure. The two grammars did not have any common chunks even in the abstract level.

The participants are not informed about this at the time of the experiment. In this phase, the participants are only required to memorize or read the series of strings presented on the computer screen in succession. After this phase, the participants are informed about the existence of rules to produce the series of strings presented in the learning phase. In the subsequent phase, the participants are asked to select grammatical strings from among those that violate the rules. It is observed that they can correctly select novel grammatical strings on more than chance level, although they are unable to report the basis of their decisions.

With respect to the unconsciousness in implicit learning, the issue about the relationship between learning and attention are one of the central topics in this area (French & Cleeremans, 2002). In the context of the AGL procedure, Dienes, Broadbent and Berry (1991) investigated the relation between AGL and divided attention using dual task procedure and the influence of division of the resource of attention was revealed. With respect to selective attention, Tanaka, Kiyokawa, Yamada, Dienes, & Shigemasu (2008) investigated the role of selective attention in AGL using GLOCAL strings (Figure 2), which are chains of compound letters(Navon, 1977). With respect to compound letters, when different letters are represented in 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 the processing of the to-be-ignored level (e.g., Hibi, Takeda, & Yagi, 2002). Given the inevitable input from the unattended level at seeing of these compound letters, GLOCAL strings allow us to simultaneously present two different strings. 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).

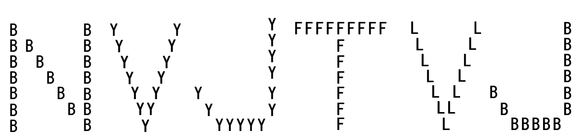

Figure 2: The example of GLOCAL strings.

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 the structure of the unattended strings can be learned. The results of their experiment revealed that the participants only learned the grammar at the level to which they attended given the interference from the unattended level.

In addition, Tanaka et al. (2008) showed that there is asymmetry between the global and local levels. More specifically, accuracy of learned grammar of the participants assigned to the global attention condition was higher than that of the participants assigned to the local attention condition, despite the participants in both conditions were equally able to write down letter strings at the attended level in the learning phase. This asymmetry suggested that the difference in visibility influences the extent they can implicitly learn given *global precedence* (e.g., Navon, 2003).

Considering the global precedence as the effect occurred in the preattentive stage of perception, the difference in AGL performance between the levels of GLOCAL strings suggested that the explanation of AGL was applied to the framework of the perceptual load theory (e.g., Lavie, 1995). Specifically, it is possible to consider that AGL performance from high perceptual load input (i.e., the local level) would be lower than that from low perceptual load input (i.e., the global level). Note that, strictly speaking, the term "perceptual load" in this study is different from its usage in the field of attention research (e.g., Lavie, 2005). First, the target presentation time is usually very short in attention research (e.g., 50–100 ms, in Lavie, 1995). Furthermore, the perceptual load was ordinarily manipulated with respect to the task-relevant display size or the number of distractors. In fact, Lavie pointed out that the reason for why much literature supported the late selection view (vs. early selection view) was that these studies used displays with usually no more than two different items and these experimental situations involved a low perceptual load (Lavie, 1995, p.452). However, given the fact that global precedence at the preattention stage of GLOCAL strings perception influences AGL, it is possible to consider that the advantage of the global attention condition in AGL was due to lower perceptual load than local attention. Furthermore, although the perceptual load was manipulated by the size of the display or the number of distractors in general, such conventional methods were inappropriate in the study of GLOCAL strings. It was possible to distract subjective viewing as compound letters by using distractors, irrespective of the perceptual load, because subjective viewing as compound letters was not constant, for instance, it depended on the size of the letters (for review, Navon, 2003).

In this experiment the luminance of GLOCAL strings was manipulated as the perceptual load. As a rationale for this operational definition, it is assumed that that attenuation of visibility based on the luminance change requires more amount of the load to percept. Moreover, the change in luminance had little influence in the structural character of GLOCAL strings rather than the existence of irrelevant stimuli. If the attenuation of visibility based on the luminance influences the implicit learning, it provides new findings about the restriction of implicit learning from environment which is subjectively uncontrollable factor. That is, it would be shown that the adaptive aspect of implicit learning in addition to the automatic aspect (e.g., Nisbett, 2003; Reber, 1989). The main hypothesis was that the perceptual load is a constraint factor for work of selective attention in AGL. More specifically, in the low luminance condition it is more difficult to learn AG from the attended information than in the high luminance condition. In a similar reason, it was predicted that the performance of the global attention condition is better than that of the local attention condition. This was also based on the motivation to replicate previous study.

Experiment

Method

Participant Forty undergraduates from Senshu University participated in the experiment. The assignments pertaining to the attention conditions and luminance of GLOCAL strings were counterbalanced.

Stimuli The two AGs used in this experiment were identical to those used in Tanaka et al. (2008) (Figure 1). Grammar 1 was the same as that used in Knowlton and Squire (1996), in terms of the abstract structure. Grammar 2 was made with the constraint that participants learned one grammar could not accurately classify stimuli from the other grammar (in detail, see Tanaka et al., 2008).

Eighteen grammatical strings were constructed from each AG with a length of three to six letters. 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, and this was reversed for the other type of GLOCAL string. Thus, these grammars were counterbalanced across both the levels. GLOCAL strings were presented as white uppercase letters against a black background. Small letters were used in 12 pt MS Gothic font. These GLOCAL strings were identical to those in Tanaka et al being used. Seven small letters were arranged vertically to obtain one large letter. 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 letter on the screen was approximately 3.2 cm and the width was approximately 1.8 to 3.0 cm. The distance between the display and the participants was approximately 60 cm. Of all the grammatical strings, those that could be judged by the grammar extracted from the attended level of the GLOCAL strings were categorized as "attended" grammatical strings, and there were "unattended" grammatical strings by the same token.

The luminance of GLOCAL strings was manipulated as a factor of perceptual load. Specifically, the luminance values of the image data of the GLOCAL strings were reduced to half by MATLAB. These GLOCAL strings with half luminance were named as the low luminance GLOCAL strings, whereas the regular GLOCAL strings were named as high luminance GLOCAL strings.

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 and were referred to as "old" grammatical strings. The remaining strings were not identical to any of the strings presented in the learning phase and were referred to as "new" grammatical strings. This distinction in grammatical strings was aimed at clarification of the extent of AGL. More specifically, the participants can judge "old" grammatical strings correctly using memory traces of presented strings, whereas they have to have some abstract structure for "new" grammar strings. All these grammatical strings were used to construct nongrammatical strings that violated both the grammars by placing one or two characters in nonpermissible locations. A constraint in the nongrammatical strings was that they comprised the same letters as the grammatical ones. For the above reason, there were four types of grammatical strings used in the learning phase, "old-attended," "new-attended," "old-unattended," and "new-unattended."

With regard to the dependent variable, the *d*' based on the signal detection theory was calculated to rule out the influence of subjective bias (Stanislaw & Todorov, 1999). The *d*' at each condition was calculated by using hit rate for grammatical strings and false alarm rate for non grammatical strings. Thus the higher the *d*' the better is the performance of the participant.

Design A 2 × 2 × 2 × 2 mixed design was employed. The first factor was luminance of the GLOCAL strings. The participants were assigned to the high or low luminance condition in the learning phase. The task and stimuli in the test phase for both conditions were identical. The second factor was global/local. The participants were instructed to attend to the global or local level in the learning phase. Luminance and global/local were between-participants factors. The third factor was attended/unattended. Half of the grammatical strings in the test phase 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. The fourth factor was familiarity. This factor was based on whether or not the grammatical strings had been presented before in the learning phase. Attention and familiarity were within-participants factors.

Procedures During the learning phase, 18 GLOCAL strings were presented on the display for 6 s, during which the participants wrote down the strings at their attended level, with each GLOCAL string being presented six times. A mask stimulus comprising many "+" signs in the area where the GLOCAL stings were intended to be displayed was presented for 1 s during the interval of the GLOCAL strings presentation. The difference between the high and low luminance conditions was only in the luminance of GLOCAL strings. The procedure in the two conditions was identical to each other.

At the beginning of the test phase, the participants were informed about the fact that each of the two levels of the GLOCAL strings followed a set of rules. The participants were required to judge whether or not each letter string is grammatical.

Table 1: Means and Standard errors for *d'* for each condition.

Attended level	Types of grammatical strings							
	Old-Attended		New-Attended		Old-Unattended		New-Unattended	
	M	SE	M	SE	M	SE	M	SE
	High luminance condition							
Global	0.875	0.152	1.051	0.199	0.023	0.144	0.330	0.106
Local	0.614	0.091	0.771	0.191	0.403	0.212	0.363	0.147
	Low luminance condition							
Global	0.770	0.188	0.645	0.184	0.489	0.154	0.051	0.141
Local	0.387	0.186	0.369	0.113	0.412	0.152	0.204	0.176

Note. M = mean *d'*, SE = standard error.

A presented string remained on display until each participant pressed one of the two specific keys. Forty grammatical and forty nongrammatical strings were presented twice in a random sequence; in other words, the participants had to provide answers for 160 strings. The attended grammar was counterbalanced: half of the participants were presented with GLOCAL strings that followed Grammar 1 at the global level and Grammar 2 at the local level in the learning phase. The other half, with the second type of GLOCAL strings that followed Grammar 1 at the local level and Grammar 2 at the global level. Moreover, half of them were instructed to attend to the global level and the other half were instructed to attend to the local level.

Results

Table 1 shows the means and standard errors of *d'* of each type of strings in each condition. At first, these *d'*s were subjected to a 2 × 2 × 2 × 2 ANOVA with luminance (high/low), global/local (attended to the global and local levels in the learning phase), attended/unattended, and familiarity (old/new).

The main effect of attended/unattended was significant ($F(1,36) = 21.09$, $\eta^2 = .118$, $p < .001$), indicating that the *d*' in the attended condition (mean = 0.686) was higher than that in the unattended condition (mean = 0.284). The interaction between attended/unattended and global/local was significant ($F(1,36) = 5.82$, $\eta^2 = .0327$, $p = .021$). The interaction between luminance and familiarity was also significant ($F(1,36) = 6.52$, $\eta^2 = .0221$, $p = .0151$).

To clarify the effect of luminance, we conducted two separate analyses by the luminance: the *d'*s were subjected to a 2 × 2 × 2 ANOVA with respect to global/local, attended/unattended, and familiarity.

In the high (regular) luminance condition, the main effect of attended/unattended was significant ($F(1,18) = 23.97$, $\eta^2 = .211$, $p < .001$), indicating that the *d*' in the attended condition (mean = 0.829) was higher than that in the unattended condition (mean = 0.280). The interaction between attended/unattended and global/local was also significant ($F(1,18) = 4.51$, $\eta^2 = .0397$, $p = .048$). The main effect and interactions related to familiarity factor were not significant (*Fs* < 2.2). The results of the simple main effect revealed that the effect of attended/unattended in the global attention condition was significant ($F(1,18) = 24.630$, $p < .001$), indicating that the *d*' of the attended condition (mean = 0.963) was higher than that of the unattended condition (mean = 0.176). In the local attention condition, the effect of attended/unattended was marginally significant ($F(1,18) = 3.847$, $p < .066$), with the same pattern as that in the global condition (mean = 0.694 in the attended condition and mean = 0.383 in the unattended condition). There were no significant differences in the effect of global/local divided by attended/unattended conditions (*Fs* < 2).

In the low luminance condition, the main effect of familiarity was significant ($F(1,18) = 4.773$, $\eta^2 = .0311$, $p = .042$), indicating that the *d*'s in the old condition (mean = 0.515) were higher than those in the new condition (mean = 0.317). The main effect of attended/unattended was marginally significant ($F(1,18) = 3.58$, $\eta^2 = .0513$, $p = .075$).

Discussion

The results revealed that the luminance of GLOCAL strings influences AGL. A four-way ANOVA revealed a significant difference between related to the luminance. Following two analyses with different luminance conditions, the results of the three-way ANOVA in the high luminance condition showed a pattern similar to that in Tanaka et al. (2008). Specifically, the effect of attended/unattended was significant, indicating that selective attention is important for AGL. Furthermore, global/local asymmetry was also found. More specifically, the *d'* in the global attention condition was higher than that in the local attention condition. This result is consistent with the fact that global processing precedes local processing (i.e., global precedence).

In contrast, the results in the low luminance condition revealed a rather different pattern. Specifically, there was no significant effect related to the attended/unattended factor, whereas the effect of familiarity was significant, suggesting that the participants could encode and store even the unattended information under the condition where they were not able to learn AG.

With respect to the difference between high and low luminance conditions, this finding could be interpreted as evidence that the effect of selective attention was restricted by the strength of visual input. Thus, AGL needs not only subjectively manipulatable top down attention and subjective visibility (cf. episodic processing, Whittlesea & Dorken, 1993), but also bottom up attention afforded by some specific physical attribute and the perceptual load, which is considered to be the source of implicit learning. Moreover, it is possible to suppose that selective attention in the AGL paradigm did not function to shut out unattended information from the environment, but to ignore to make a cognitive representation (cf. Moran & Desimone, 1985). Note that every participant could write down letter strings from the instructed level of GLOCAL strings, although some participants missed writing down a few strings because of a few minutes' absent-mindedness, regardless of the experimental manipulation. Furthermore, none of the participants in the low luminance condition claimed that GLOCAL strings were too dark to see in the learning phase. In other words, every participant could convert the visual stimuli into motor action via mental processing based on letter recognition. Thus, it is possible to state that the attenuation of input in the low luminance condition results in the disruption of AGL.

Given the assumption that the whole resource of attention is constant, it could be interpreted as follows. The participants in the low luminance condition tried to attend to the specific level of GLOCAL strings by consuming relatively more resource than that in the high luminance condition. As a result, they failed to inhibit information from the unattended level and failed to extract AG from even the attended level of GLOCAL strings. This explanation based on constant attention could be applied to all the results of this study. For example, AGL performance in the global attention condition was higher than that in the local attention condition because (1) attending to the global level was easier than attending to the local level and (2) inhibiting irrelevant information from the local level was easier than from the global level.

This finding was consistent with Reber's (1967) speculation in relation to perceptual learning and P. J. Reber and Squire's (1999) suggestion from the fact that patients with Parkinson's disease exhibited normal AGL. With respect to the SRT task, some studies showed that SRT learning was predominantly nonmotoric, for instance, SRT learning can transfer from three fingers to one (Cohen, Ivry, & Keele, 1990). Moreover, it is said that SRT learning can occur in the task with observation alone (e.g., Remillard, 2003). It is certain that implicit learning abilities observed in an SRT task are complex and composed of various learning factors(e.g., motor learning and position learning). AGL does not simply reflect the abstract structural properties of stimuli but also the exact visual form of the stimuli. In sum, although implicit learning needs compulsive input from the external world, it is necessary to enhance raw input to assign adequate amount of attention. This assumption allows us to reconstruct the definition of implicit learning as a result of active intention for adaptation, although it could be beyond attention control as subjective activity.

Furthermore, the main effect of familiarity in the low luminance condition can be interpreted as evidence that the unattended information of GLOCAL strings was encoded inevitably. However, during the later process, the unattended information might be suppressed as a redundant one while the attended information is enhanced to make useful representation for subjective adaptation in the novel situation (c.f., Cock, Berry & Buchner., 2002; Jiang & Leung, 2005). In contrast, there was no significant difference about familiarity in the high luminance condition. It can be interpreted as evidence that the participants learned AG judged grammaticality using abstract information from the attended level other than presented strings themselves in the learning phase (cf. Pothos & Bailey, 2000).

According to the framework based on the linkage of resource in subsystems, it is possible to make the following predictions. For example, apart from the active inhibition system, if the perceptual load at the global level of GLOCAL strings was relatively lower than that at the local level, then the *d'* of the attended and/or unattended grammar in the global attention condition would be higher than that in the local condition. In other words, it is possible to assign a surplus resource to arbitrary subsystems. The assumption that input attention and central attention are inextricably linked may cause this ambiguity. Furthermore, this theory included an implicit assumption that all finite resources were assigned to every ongoing system, which the experimenter assumed as an experimental procedure. Future research is needed to resolve these problems for the application of the findings of perceptual load theory to AGL study.

The result of this study implies that AGL needs active information processing while selective attention plays the role of inhibition from an irrelevant input. Moreover, irrespective of attention, the strength of the visual input influences AGL. Implicit learning is an adaptive system involving the factor of perceptual learning, abstract structural learning, and motor skill learning as inner mechanisms, sensitivity to inevitable input from environment, and subjective intention as a form of consciousness.

References

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

Cohen, A., Irvy, R. I., & Keele, S. W. (1990). Attention and structure in sequence learning. *Journal of Experimental Psyhcology,: Learning, Memory, and Cogntintion*, *16*, 17–30.

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

French, R. M., & Cleeremans, A. (2002). *Implicit learning and consciousness: An empirical, philosophical and computational consensus in the making.* Hove, UK: Psychology Press.

Hibi, Y., Takeda, Y., & Yagi, A. (2002). Global interferences: 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.

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, and Cognition, 22,* 169–181.

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human, Perception, and Performance, 21,* 451–468.

Lavie, N. (2005). Distracted and confused: Selective attention underload. *Trends in Cognitive Sciences, 9*, 75–82.

Moran, J., & Desimone, R. (1985). Selective attention gates visual processing in the extrastriate cortex. *Science, 229*, 782–784.

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. (2003). *The Geography of Thought: How Asians and Westerners Think Differently*. The Free Press: New York.

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

Reber, A. S. (1967). Implicit learning of artificial grammars. *Journal of Verbal Learning and Verbal Behavior*, *77,* 317–327.

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

Reber, P. J., & Squire, L. R. (1999). Intact learning of artificial grammars and intact category learning by patients with Parkinson's disease. *Behavioral Neuroscience, 113,* 235–242.

Remillard, G. (2003). Pure perceptual-based sequence learning. *Journal of Experimental Psyhcology,: Learning, Memory, and Cogntintion*, *29*, 581–597.

Stanislaw, H., & Todorov, N. (1999). Calculation of signal detection theory measures. *Behavior Research Methods, Instruments, and Computers, 31*, 137–149.

Tanaka, D., Kiyokawa, S., Yamada, A., Dienes, Z & Shigemasu, K. (2008). Role of selective attention in artificial grammar learning. *Psychonomic Bulletin & Review, 15*, 1154–1159.

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.