

Construction of patterns considering spatial configuration between radicals of Japanese Kanji and their complexity ratings

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We newly constructed patterns to evaluate spelling errors in Japanese Kanji. The patterns were constructed based on spatial configuration between components (radicals) of Kanji. We manipulated the spatial complexity of the patterns based on Garner's equivalent set size (ESS): ESS-1, ESS-2, and ESS-4 patterns (simple to complex). To examine pattern validity, we conducted a rating task in which forty participants rated the complexity of the patterns. ESS-4 patterns were rated as more complex than ESS-1 and ESS-2 patterns (the complexity was the similar between ESS-1 and ESS-2 patterns). Moreover, we also found differences in complexity among ESS-4 patterns (three ranges of complexity: small, medium, and large). These results could be explained by the theory of intra-configuration transformation structures and the number of objects in addition to the ESS. The patterns of ESS-1 and ESS-2 included all symmetry axes (vertical, horizontal, and diagonal axes), implying higher symmetry and rated as simple. The patterns of ESS-4 (complexity: small) had 2 objects whereas the patterns of ESS-4 (medium) had 3 objects, although both patterns included diagonal axes. Because of the number of objects, the patterns of ESS-4 (medium) might be rated as more complex than those of ESS-4 (small). The patterns of ESS-4 (large) included any one of the symmetry axes (vertical, horizontal, and diagonal axes), suggesting lower symmetry and rated as complex. These results indicated the higher validity of the patterns constructed in the present study in terms of spatial complexity.

Key words: Spatial complexity; Equivalent set size; Intra-configurational transformation structures; Spelling errors in Kanji

Developmental dyslexia is a part of specific learning disorder (DSM-5: American Psychiatric Association, 2013). Children with developmental dyslexia generally exhibit specific reading and spelling errors such as taking time to read letters and sentences, misreading, miswriting, and reversal errors. Considering that such children have normal intelligence and intact vision and hearing, it is natural to think that their difficulty may be caused by perceptual and cognitive skills.

Considering perceptual and cognitive skills, many previous studies have examined the factors of difficulties in children with developmental dyslexia. A series of studies by Lachmann focused on visual and phonological processing in children with developmental dyslexia (Lachmann, Berti, Kujala, & Schröger, 2005; Lachmann, Schumacher, & van Leeuwen, 2009; Lachmann & van Leeuwen, 2007). Specifically, Lachmann and van Leeuwen (2007) focused on symmetry perception and proposed the Functional Coordination Deficit model. Since visual pattern recognition is defined by symmetry generalization based on the Gestalt factor in which symmetry generalization enhances object encoding and memory (e.g., Garner & Sutliff, 1974,

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Rauschenberger & Yantis, 2006; Takahashi, Hidaka, Teramoto, & Gyoba, 2013), mirror images included in other transformations of the image pattern are naturally generated (see also, Garner & Clement, 1963). Both the pattern image and its mirror image are stored together in representation, which suggests that it is difficult to discriminate between these images. This means that symmetry generalization interferes with learning letters in integration between the correct visual image and phonological information, and then, observers have difficulty knowing whether the correct visual image or its mirror image should be integrated with phonological information. In the case of the alphabet, when an observer sees “p,” he or she generalizes the visual images of “p” and “q” based on the symmetry generalization system. Although the observer has difficulty knowing whether the visual image of “p” or “q” should be integrated with the phonological information of “pee,” observers with typical development can discriminate “p” and “q” and integrate with phonological information because they suppress the symmetry generalization. However, because children with developmental dyslexia may fail to suppress the symmetry generalization, they show difficulty in reading and spelling.

Although these previous studies have proposed important findings, they used alphabet or numeric characters as experimental stimuli. In Japan, we should examine Kanji characters as experimental stimuli to reveal the properties of developmental dyslexia. Many Kanji characters have various components (radicals) whereas there is no concept of components in alphabet or numeric characters. Kanji characters have various radicals which construct spatial configuration arrayed in right and left or top and bottom. Thus, we must consider the effect of spatial configuration on reading and spelling of Kanji characters because our perceptual system is based on the Gestalt factor (e.g., symmetry), which affects the efficacy of perception. Although some previous studies focused on spatial configuration between radicals and discussed important findings (Leong, 1999; Leong, Cheng, & Lam, 2000), they did not reveal the effects of spatial configuration between radicals on reading and spelling.

To examine the effects of spatial configuration between radicals of Kanji, we refer to the theory of Equivalent Set Size (ESS: Garner, 1962; Garner & Clement, 1963). Based on the rotation and reflection transformation principle, ESS assumes different possible alternations. For example, ESS-1 pattern has the same clockwise rotations and reflections (one pattern is assumed). ESS-4 pattern contains four possible clockwise rotations (0° , 90° , 180° , and 270°) and the same reflections (four patterns are assumed). ESS-8 pattern has four possible clockwise rotations and four reflections (eight patterns are assumed). The smaller ESS patterns have fewer possible transformation patterns, suggesting that the patterns have higher redundancy (recognized as simple, symmetrical, and stable). ESS was shown to have higher validity in previous studies (e.g., Garner & Sutliff, 1974, Rauschenberger & Yantis, 2006; Takahashi et al., 2013).

The present study aimed to newly construct the patterns considering spatial configuration between radicals of Kanji characters. Based on ESS, we manipulated pattern complexity. To examine the validity of the patterns, we conducted a rating task to measure complexity. If the patterns are correctly constructed and have higher validity based on ESS, we assume that

pattern complexity may be larger with increased ESS because the larger ESS patterns have more possible transformation patterns.

Method

Participants

The participants were 40 graduate and undergraduate students (11 men and 29 women; mean age = 20.03, SD = 1.17). All participants had normal or corrected-to-normal visual acuity. Informed consent was obtained from each participant prior to participation.

Stimuli

Based on ESS (Garner, 1962; Garner & Clement, 1963), we made the experimental patterns referring to spatial configuration between radicals of Kanji characters designated for daily use in Japan (Figure 1). In each pattern (4×4 cm), gray parts represent arrayed radicals (Figure 2a). We controlled the size of gray and white areas in all patterns.

Procedure

Each participant rated at his/her own pace the 18 patterns (presented in Figure 2a) on a printed paper using 6-point scales (1: simple to 6: complex) in a group setting. The order of patterns was counterbalanced across participants.

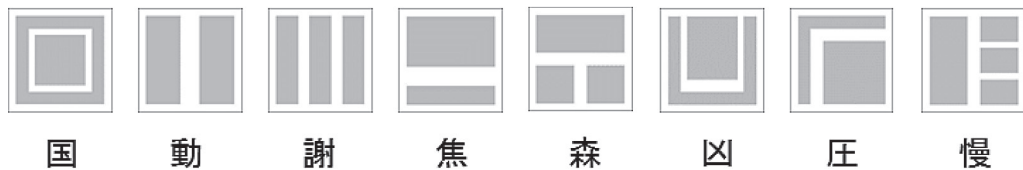


Figure 1. Example patterns made by the authors referring to spatial configuration of radical of Kanji characters designated for daily use in Japan.

Results

We averaged the complexity of the patterns including rotation transformation (e.g., patterns [2] and [3] were averaged as the rating of ESS-2_a in Figure 2a) and conducted one-way ANOVA with all patterns as the within-participants factor (8). Figure 2b shows the results. We found the main factor of pattern [$F(7, 273) = 58.39, p < .001, \eta_p^2 = .60$]. Post hoc tests (Ryan's method) showed no differences among ESS-1, ESS-2_a, and ESS-2_b [ESS-1 vs. ESS-2_a: $t(273) = 2.11, n.s.$; ESS-1 vs. ESS-2_b: $t(273) = 0.53, n.s.$; ESS-2_a vs. ESS-2_b: $t(273) = 2.64, n.s.$] or among ESS-4_c, ESS-4_d, and ESS-4_e [ESS-4_c vs. ESS-4_d: $t(273) = 1.21, n.s.$; ESS-4_c vs. ESS-4_e: $t(273) = 1.36, n.s.$; ESS-4_d vs. ESS-4_e: $t(273) = 2.56, n.s.$], whereas there were significant differences among other patterns [ESS-1 vs. ESS-4_a: $t(273) =$

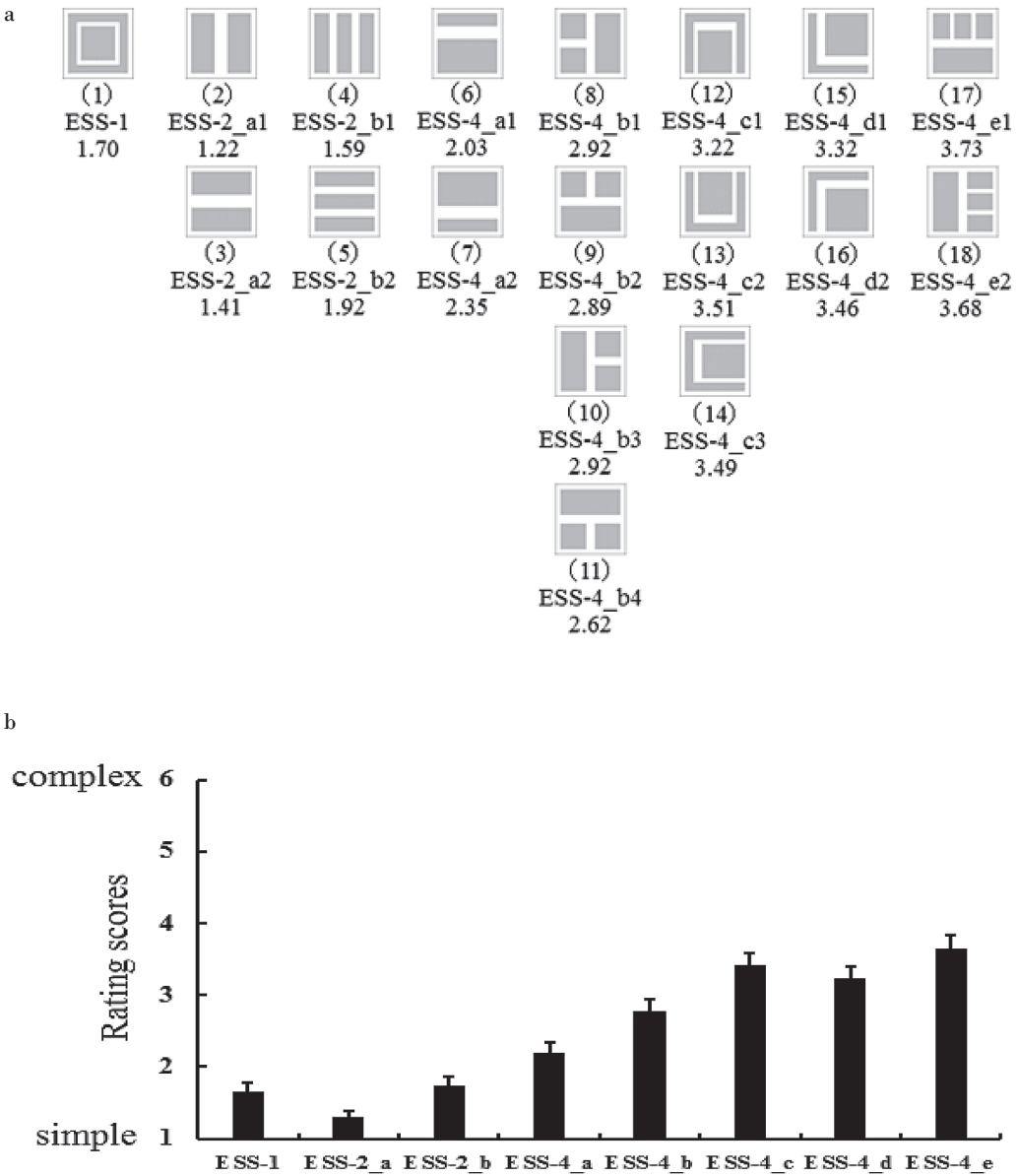


Figure 2. a: All patterns used in this experiment. The upper, middle, and lower represent pattern number, ESS, and complexity (1: simple to 6: complex), respectively.
b: Results of the pattern rating scores. Error bars denote standard error of the mean.

3.24, $p < .05$; ESS-1 vs. ESS-4_b: $t(273) = 6.78$, $p < .05$; ESS-1 vs. ESS-4_c: $t(273) = 10.70$, $p < .05$; ESS-1 vs. ESS-4_d: $t(273) = 9.50$, $p < .05$; ESS-1 vs. ESS-4_e: $t(273) = 12.06$, $p < .05$; ESS-2_a vs. ESS-4_a: $t(273) = 5.35$, $p < .05$; ESS-2_a vs. ESS-4_b: $t(273) = 8.89$, $p < .05$; ESS-2_a vs. ESS-4_c: $t(273) = 12.81$, $p < .05$; ESS-2_a vs. ESS-4_d: $t(273) = 11.61$, $p < .05$; ESS-2_a vs. ESS-4_e: $t(273) = 14.17$, $p < .05$; ESS-2_b vs. ESS-4_a: $t(273) = 2.71$, $p < .05$; ESS-2_b vs. ESS-4_b: $t(273) = 6.26$, $p < .05$; ESS-2_b vs. ESS-4_c: $t(273) = 10.18$, $p < .05$; ESS-2_b vs. ESS-4_d: $t(273) = 8.97$, $p < .05$; ESS-2_b vs. ESS-4_e: $t(273) = 11.53$, $p < .05$; ESS-4_a vs. ESS-4_b: $t(273) = 3.54$, $p < .05$; ESS-4_a vs. ESS-4_c: $t(273) = 7.46$, $p < .05$; ESS-4_a vs. ESS-4_d: $t(273) = 6.26$, $p < .05$; ESS-4_a vs. ESS-4_e: $t(273) = 8.82$, $p < .05$; ESS-4_b vs. ESS-4_c: $t(273) = 3.92$, $p < .05$; ESS-4_b vs. ESS-4_d: $t(273) = 2.71$, $p < .05$; ESS-4_b vs. ESS-4_e: $t(273) = 5.28$, $p < .05$].

These results showed that complexity increased in these groups; among ESS-1, ESS-2_a, and ESS-2_b; among ESS-4_a; among ESS-4_b; and among ESS-4_c, ESS-4_d, and ESS-4_e.

Discussion

The present study aimed to construct patterns considering spatial configuration between radicals of Kanji characters and to measure complexity to confirm the validity of the patterns. Based on ESS (Garner & Clement, 1963), we manipulated complexity and constructed the patterns. Using the patterns, we conducted a rating experiment to measure the complexity of each pattern.

We found differences in complexity within each pattern. We predicted that complexity may be larger with increased ESS. As predicted, the patterns of ESS-4 were rated as the most complex compared with the patterns of ESS-1 and ESS-2. However, complexity of the patterns of ESS-1 were similar to the patterns of ESS-2. Moreover, there were differences in complexity rating scores among ESS-4 patterns, i.e., the patterns of ESS-4 were divided into 3 groups (complexity: small, medium, and large), although there was no difference in complexity among the patterns of ESS-4 based on ESS.

Since we cannot fully interpret our results in terms of the ESS, we need other explanations. We assume that these results can be explained by the theory of intra-configurational transformation structures (Matsuda, 1978) and the effects of the number of objects constructed with the patterns (Takahashi, Kawachi, & Gyoba, 2012) in addition to ESS. Matsuda (1978) proposed the theory of intra-configurational transformation structures in which pattern complexity (or pattern goodness) may be changed depending on symmetry axes (vertical, horizontal, and diagonal axes) even if the patterns include the same ESS value. When the number of symmetry axes included in the pattern is increased, the pattern is rated as simple. Moreover, Takahashi et al. (2012) indicated that pattern complexity is varied depending on the number of objects included in the pattern even if the ESS value is controlled. When the number of objects is decreased including the pattern, the pattern is rated as simple.

Based on these findings, all patterns were divided into 4 groups in terms of complexity: group 1: the patterns of ESS-1, ESS-2_a, and ESS-2_b; group 2 (complexity: small): the patterns of ESS-4_a; group 3 (complexity: medium): the patterns of ESS-4_b; and group 4 (complexity: large): the patterns of ESS-4_c, ESS-4_d, and ESS-4_e. Now, we can explain our present results as follows. The patterns of ESS-1 and ESS-2 (group 1) had all symmetry axes (vertical, horizontal, and diagonal axes), suggesting higher symmetry, and the participants rated them as the simplest patterns. The patterns of ESS-4 (group 2: small complexity) had 2 objects whereas the patterns of ESS-4 (group 3: medium) had 3, although both patterns contained a tendency of diagonal axes. Considering the number of objects, the patterns of ESS-4 (medium complexity) might be rated as complex compared with the patterns of ESS-4 (small complexity). The patterns of ESS-4 (large complexity) had any one of the symmetry axes (vertical, horizontal, and diagonal axes), implying lower symmetry, and the participants rated them as the most complex patterns. Regarding ESS, the intra-configurational transformation structures, and the number of objects, we assume that the patterns constructed by our study may have higher validity to examine spatial configuration between radicals of Kanji in terms of complexity.

Since our study showed the validity of the patterns, we speculate that the patterns may be effective to analyze reading and spelling errors in Kanji in terms of spatial complexity. Future study may examine reading and spelling errors in children with developmental dyslexia using the patterns, providing evidence of a mechanism for the errors.

Conclusion

We newly constructed patterns focusing on spatial configuration between radicals of Japanese Kanji characters and conducted a complexity rating task to confirm the validity of the patterns. We found that the patterns had higher validity, which can be explained by ESS, the intra-configurational transformation structures, and the number of objects. Future research may analyze the mechanism of reading and spelling errors in children with developmental dyslexia using the patterns presented by our study.

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