Junichi Takahashi, Yousuke Kawachi & Jiro Gyoba

# Visual Short-Term Memory is Modulated by Visual Preference for Spatial Configuration Between Objects

## Introduction

The visual system has a limited capacity for processing sensory input. In order to adapt to the surrounding environment, the visual system needs to create meaningful representations of the physical environment from tremendous amounts of sensory input and maintain these representations over time, within this limited capacity. These representations are one of the critical products of visual processing, which is called visual short-term memory (hereafter referred to as VSTM).

Jiang, Olson & Chun (2000) indicated two questions about VSTM; the capacity of VSTM and the representations of VSTM. The first question involves the capacity of VSTM (the number of objects that can be stored therein; Alvarez & Cavanagh 2004; Luck & Vogel 1997; Phillips 1974). Luck & Vogel (1997), along with many other researchers, have shown that the capacity of VSTM is limited to approximately five objects without depending on the number of features embedded in the objects. The second question concerns the factors of objects represented in VSTM. Representations in VSTM are reported to be less detailed than had been expected (Intraub 1997; O'Regan, Rensink & Clark 1999; Rensink, O'Regan & Clark 1997), although it was recently reported that the complexity of the factors could influence the capacity of VSTM (e.g., Alvarez & Cavanagh 2004). The scope of more recent studies has been extended from a prior focus on the objects themselves to a current focus on the spatial relations between objects. Jiang et al. (2000) examined this using a change-detection task (see Section 3). In the change-detection task, various colored objects (squares) were arrayed in each quadrant. Participants judged the presence or absence of color changes between successive memory and test displays (memorizing the spatial locations for each object was not necessary). Experimental conditions comprised three types of test displays: probes with the same locations, probes with different locations but the same configurations, and probes with different locations and configurations. Their results showed that memory accuracy was lowest for the condition with different contexts (different locations and configurations) compared with the

*GESTALT THEORY*

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other two conditions. These results indicated that VSTM of object features (color) is modulated by spatial configurations, meaning that VSTM mainly stores spatial configurations between objects. Alvarez & Oliva (2007) examined the effects of spatial "regularity" in the global spacing between objects on VSTM. This regularity of spatial configuration was quantified by measuring the distance between each pair of objects, calculating the standard deviation of these distances, and dividing it by the mean. The results showed that memory performance was better for a change of spatial configuration that disrupts the regularity than for one that did not alter the regularity, regardless of the magnitude of regularity between successive visual displays. These findings suggest that the spatial configuration between objects has an important role in VSTM representation.

The issue of spatial regularity has often been linked to Gestalt laws: the principle of "pattern goodness" or "Prägnanz" (Gyoba 2007; Hermens, Lachmann & van Leeuwen 2015; Lachmann & Geissler 2002; Lachmann & van Leeuwen 2005a, 2005b, 2007; Makovski & Jiang 2008; Takahashi, Kawachi & Gyoba 2012; Takahashi, Hidaka, Teramoto & Gyoba 2014; Wertheimer 1912). Gestalt psychology has investigated some Gestalt factors such as proximity, similarity, continuation, and symmetry (Van der Helm & Leeuwenberg 1996). There has been no good unifying concept for the perception of pattern goodness (Garner & Clement 1963). Thus, Garner & Clement (1963) proposed that pattern goodness can be explained by the concept of "redundancy" in information theory. To manipulate redundancy quantitatively, Garner & Clement (1963) proposed that pattern goodness was inversely related to the size of psychologically inferred sets. These can be defined by the number of alternative representations forming the sets of patterns (Equivalence Set Size: ESS; Garner 1962; Garner & Clement 1963). Based on rotation and reflection (rotation and reflection transformation principle; Garner 1962; Garner & Clement 1963; Garner & Sutliff 1974; Howe 1980; Sebrechts & Garner 1981), subsets of ESS transformationally produce patterns with three values of 1, 4, and 8 (which are ESS 1, 4, and 8, respectively). Patterns tend to be judged as good when the ESS is relatively small (Figure 1). Good patterns are also perceived as stable, symmetric, or simple. On the other hand, poor patterns are perceived as unstable, asymmetric, or complex. Moreover, previous studies have reported that the ESS can influence performance on memory tasks (Garner & Sutliff 1974; Howe 1980; Sebrechts & Garner 1981; Lachmann & van Leeuwen 2005a, 2007, 2010; Lachmann & Geissler 2002), visual search tasks (Makovski & Jiang 2008; Rauschenberger & Yantis 2006), and rapid serial visual presentation tasks (Takahashi et al. 2014).

As mentioned above, goodness, symmetry, and complexity (we labeled these physically-related variables) are important factors in pattern recognition. However, in general, observers also perceive other psychological variables, such as preference, beauty, and pleasure (we labeled these affectively-related variables) when viewing objects. Gyoba (2007) investigated the subordinate factors involved in spatial configurations consisting of five dots (Garner & Clement 1963), using the semantic differential (SD) method (Osgood, Suci & Tannenbaum 1957): the SD method can reveal affectively-related variables when viewing various stimuli, such as objects, line drawings, or faces. Gyoba (2007) showed that the pattern recognition of spatial configurations was influenced by several affectively-related variables, such as preference, pleasure, and beauty, in addition to physically-related variables such as regularity, symmetry, and complexity. Takahashi et al. (2012) also demonstrated a similar tendency by using five-, seven-, and nine-dot configurations. These results suggested that not only physically related variables, but also affectively related variables can affect pattern recognition. We interpreted these findings as follows: if physically related variables, such as goodness of spatial configuration defined by ESS, modulate memory performance (e.g., Garner & Sutliff 1974), affectively related variables, such as preference of spatial configuration, may also modulate memory performance. The aim of the current study was to investigate whether the affective properties (especially visual preference[1]) of spatial configurations among objects modulate VSTM. Preference-related decision-making is suggested to be a fundamental evaluative mechanism that precedes many cognitive processes (Amir, Biederman & Hayworth 2011; Kim, Adolphs, O'Doherty & Shimojo 2007; Shimojo, Simon, Shimojo & Scheier 2003; Zajonc 1980). Previous studies have regarded visual preference as a potent component of VSTM representations (Jackson, Wu, Linden & Raymond 2009; Öhman, Flykt & Esteves 2001) and have examined whether the affective properties of objects (e.g., angry faces or fearful objects) modulate VSTM. Jackson et al. (2009) suggested that VSTM of angry faces was enhanced compared with that of happy or neutral faces. They suggested that threatening emotions, such as anger, would be ecologically important and might influence the decision of whether or not to approach a stimulus. If so, observers need to be able to accurately memorize angry faces in VSTM.

Whether the affective properties of spatial configurations modulate VSTM representations has yet to be examined, although the spatial configuration among objects does play an important modulating role in VSTM (Alvarez & Oliva 2007; Jiang et al. 2000). If negative stimuli enhance VSTM, we consider the possibility that memory performance for objects located in dislikable configurations might be higher than that for objects located in likable configurations. In order to examine this possibility, we used five, seven, and nine dots located in various

[1] We use "visual preference" to refer to the distinction of whether participants like or dislike the patterns (see also, Amir et al., 2011; Bear, 1973).

spatial configurations and conducted a memory task in Experiment 1. In addition, in Experiment 2, we examined the possibility that visual preference for spatial configurations would affect VSTM not only of spatial locations, but also of features embedded in objects. We presented five-, seven-, and nine-line segments with orientations arrayed in the same spatial configurations used in Experiment 1. In these experiments, we compared the VSTM capacity between dislikable and likable configurations.

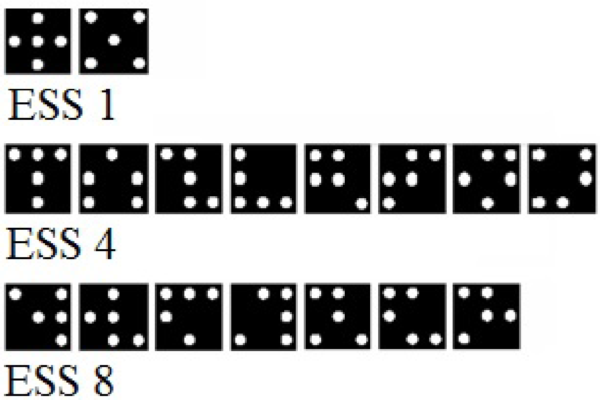


**Fig. 1** Example of Garner & Clement's (1963) five-dot configurations based on the rotation and reflection transformation principle. For ESS 1, alternative representations are not produced by clockwise rotation and reflection. For ESS 4, rotation transformation produces four clockwise rotations, but not reflection. Furthermore, ESS 8 contains four alternative representations by clockwise rotations or reflections, respectively. We used only ESS 8 configurations that include five-, seven-, and nine-dot configurations.

## Experiment 1

### VSTM of Spatial Locations Modulated by Visual Preference for Spatial Configurations

We examined whether visual preference could affect spatial-location VSTM by using five-, seven-, and nine-dot locations.

### Method

*Participants*

Eight participants (age range: 21–25 years; four men and four women) were recruited from Tohoku University graduate and undergraduate students who were naive to the purpose of the experiment. They all had normal or corrected-to-normal visual acuity and provided informed consent before participating. The ethics committee of the Graduate School of Arts and Letters at Tohoku University approved the study protocol.

*Stimuli*

Presentations of stimuli and data collection were controlled by a computer (Precision 390, DELL). All stimuli were generated using MATLAB (Mathworks, Inc.) and Cogent Graphics (http://www.vislab.ucl.ac.uk/Cogent/index.html); they were displayed on a CRT monitor (Trinitron GDM-FW900, SONY) with a 60-Hz refresh rate. Each spatial configuration (Figure 2 [a]) consisted of five, seven, or nine circular white dots (64.0 cd/$m^2$, a diameter of 1.4 degrees of visual angle) placed in imaginary cells of a 5 × 5 matrix on a black background (0.5 cd/$m^2$); each spatial configuration was isomorphic under all rotations and reflections. As mentioned previously, Garner & Clement (1963) referred to the number of equivalents that can be generated by rotation and reflection transformations as the equivalent set size (ESS). Each of the spatial configurations in this study belonged to a set with eight equivalents (ESS 8). Thus, the memory load or redundancy of these spatial configurations could be controlled (see Figure 1) based on Garner's rotation and reflection transformation principle (Garner & Clement 1963; Howe 1980). There were a total of 56 spatial configurations in the five-dot locations (7 sets with 8 equivalent spatial configurations each; Garner & Clement 1963), 40 spatial configurations in the seven-dot locations (5 sets with 8 equivalent spatial configurations each, created based on Howe's [1980] procedures), and 64 spatial configurations in the nine-dot locations (8 sets with 8 equivalent spatial configurations each; Howe, 1980).

*Procedure*

We used a same-different task (Figure 2 [b]). A participant sat on a seat approximately 60 cm away from the CRT monitor with his/her head resting on a chinrest. At the beginning of each trial, a fixation cross was presented for 500 ms at the center of the screen. Next, a memory display that contained several dots was presented for 100 ms. After this, a mask stimulus (square lattice pattern) was presented for 100 ms, followed by a blank display for 1500 ms, and then a test display containing one dot (single probe) appeared for 100 ms. In half of the trials, the single dot of the test display appeared at the same location as one of the dots in the memory display; in the other half of the trials, the single dot of the test display appeared at a different location from the dots in the memory display. Then, a blank display was presented until participants responded. Participants were instructed to judge whether the dot location in the test display was the same as or different from any of the dots in the memory display. Accuracy rather than speed was emphasized.

The participants each completed three blocks, totaling 640 trials: 2 conditions (same and different) × 160 configurations (56, 40, and 64 configurations using five, seven, and nine dots respectively) × 2 trials per configuration. The order of the number of dots (five-, seven-, and nine-dot configurations) was counterbalanced across the participants. After the change-detection task, they were incidentally asked to rate their preferences for all 56 (five-dot locations), 40 (seven-dot locations), and 64 (nine-dot locations) configurations presented at the center of the display.

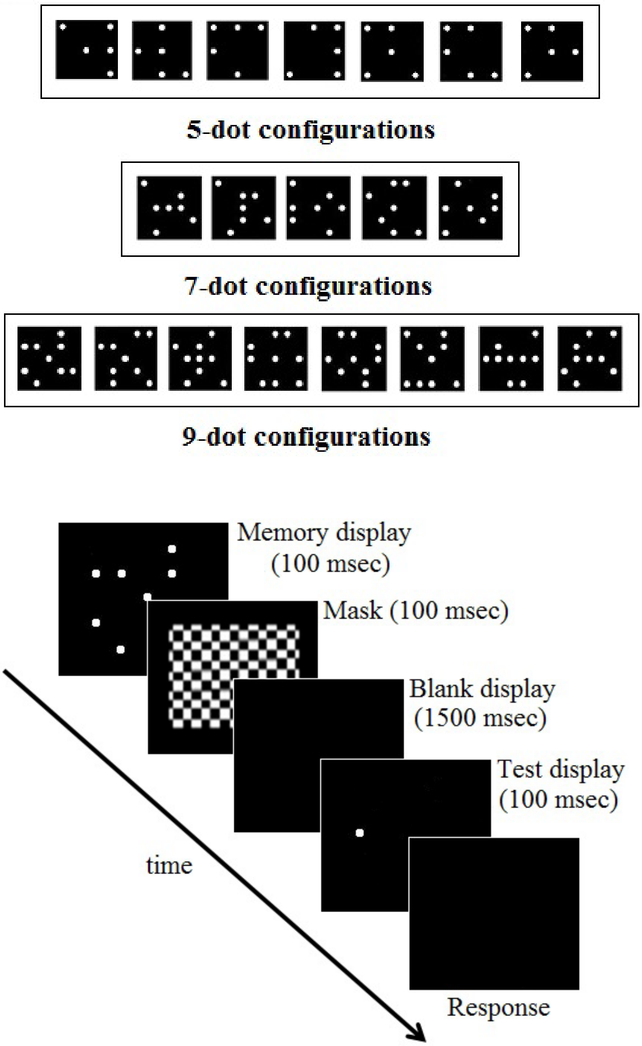


**Fig 2.** Samples of the spatial configuration and schematic representation of a stimulus sequence used in Experiment 1. (a) The five-dot configurations consisted of five dots on the virtual 5 × 5 matrix used by Garner & Clement (1963). The seven-dot configurations consisted of seven dots on the virtual 5 × 5 matrix, which was created on the basis of Howe's (1980) procedures. The nine-dot configurations consisted of nine dots located on the virtual 5 × 5 matrix, adopted from Howe (1980). (b) The change-detection task used in Experiment 1. The example shows the different condition when the number of dots is 9.

## Results and Discussion

To examine the effects of visual preference on spatial-location VSTM, the participants classified each of the spatial configurations as either dislikable (1 to 2 points) or likable (4 to 5 points) in each condition, according to the visual preference rating scores of each participant. We excluded configurations with preference rating scores of 3 from the following analysis because observers' informal reports suggested that participants tended to use the score of 3 to signify "I don't know." Some participants reported that since they experienced difficulty rating the preference of dot patterns, they selected a rating score of 3 when they could not decide how much they liked or disliked these dot patterns. It was doubtful to treat preference rating scores from 1 to 5 as a continuous scale. Thus, we excluded rating scores of 3 and categorized rating scores of 1 or 2 as dislikable, and scores of 4 or 5 as likable in the ANOVA.

We calculated the memory performance for each condition based on each participant's individual ratings [i.e., the responses of Participant 1 (P1) were analyzed in terms of P1's ratings]. Among the five-dot locations, 37 % of the configurations were rated as dislikable and 33 % were rated as likable. Among the seven-dot locations, 37 % of the configurations were rated as dislikable and 45 % were rated as likable. Among the nine-dot locations, 40 % of the configurations were rated as dislikable and 39 % were rated as likable. We confirmed that there were no significant differences between the proportions of the configurations rated as dislikable and likable in the five-, seven-, and nine-dot location conditions by performing a two-way ANOVA with visual preference (2: dislikable or likable) and location (3: five-, seven-, nine-dot locations) as within-participants factors [main effect of visual preference: $F(2, 14) = 2.21$, $p = .15$, $\eta_p^2 = 0.24$; interaction between visual preference and locations: $F(2, 14) = 1.09$, $p = .36$, $\eta_p^2 = 0.13$].

We estimated the capacity of VSTM (Cowan, 2001) from the percentage of correct responses on the change-detection task using the following equation:

$$K = (H - FA) * N,$$

where $K$ is the capacity of VSTM, $H$ is the hit rate (the rate of correctly reporting a change when the location of the dot was different in the two displays), $FA$ is the false alarm rate (the rate of incorrectly reporting a change when the location of the dot was the same in the two displays), and $N$ is the number of dots arrayed in the change-detection task. Creating an index of VSTM capacity is useful because not only is it easy to interpret the results in terms of the upper limit on the number of objects stored in VSTM, but the index also excludes response bias (Alvarez & Cavanagh 2004, 2008).

We performed a two-way analysis of variance (ANOVA) with visual preference and the number of dots as within-participants factors (Figure 3). There was a significant main effect of visual preference [$F(1, 7) = 7.72$, $MSE = 0.14$, $p < .05$, $\eta_p^2 = 0.52$] and a significant interaction between visual preference and the number of dots [$F(2, 14) = 6.59$, $MSE = 0.31$, $p < .01$, $\eta_p^2 = 0.48$]. This interaction revealed a simple main effect of visual preference only in the nine-dot locations [$F(1, 21) = 20.00$, $MSE = 0.25$, $p < .001$, $\eta_p^2 = 0.49$]. The memory performance for dislikable configurations was significantly better than for likable ones only in the nine-dot locations. Moreover, with regard to the simple main effect of the number of dots, a significant difference was observed for the dislikable configurations [$F(2, 28) = 5.46$, $MSE = 1.10$, $p < .01$, $\eta_p^2 = 0.28$], but not for the likable configurations [$F(2, 28) = 0.28$, $MSE = 1.10$, $p = .76$, $\eta_p^2 = 0.02$]. A post-hoc test (Tukey's HSD method) revealed that in the dislikable configurations, the memory performance for the nine-dot locations was better than for the five- and seven-dot locations [five- vs. seven-dot locations: $t(28) = 0.69$, $p = .50$; five- vs. nine-dot locations: $t(28) = 2.46$, $p < .05$; seven- vs. nine-dot locations: $t(28) = 3.14$, $p < .05$]. However, a main effect for the number of dots was not observed [$F(2, 14) = 2.26$, $MSE = 1.89$, $p = .14$, $\eta_p^2 = 0.24$].

One might argue that the separation of dislikable and likable configurations was based on an arbitrary criterion (i.e., dislikable and likable configurations included rating scores 1 and 2, and 4 and 5, respectively. Moreover, the exclusion of rating scores of 3 suggests a reduced sample size. Some readers might consider that rating scores of 1, 2, 3, 4, and 5 indicate very dislikable, dislikable, neutral, likable, and very likable, respectively). In order to examine this possibility, we conducted a single regression analysis including all data for nine-dot locations in which we observed significant effects in the ANOVA results. The analysis revealed a marginally significant difference only for nine-dot locations (adjusted $R^2 = .56$, $p = .09$); the higher the rating scores, the smaller the capacity of VSTM. These results were consistent with the ANOVA results.

There was no significant difference between the two visual preference classes for the five- and seven-dot locations. Therefore, our results indicated an effect of visual preference on spatial-location VSTM when there were more than seven dots to store in VSTM. Considering previous reports that the capacity limit of spatial-location VSTM is around seven locations (Franconeri, Alvarez & Enns 2007), we suggest that the superiority of the VSTM capacity for dislikable configurations can be seen when the number of dots is over the capacity limit.

These findings revealed that visual preference for spatial configurations between objects can be regarded as a potentially influential factor in spatial-location VSTM representation. This superiority of dislikable configurations may be consistent with findings from previous studies (Jackson et al. 2009; Öhman, Flykt et al. 2001).

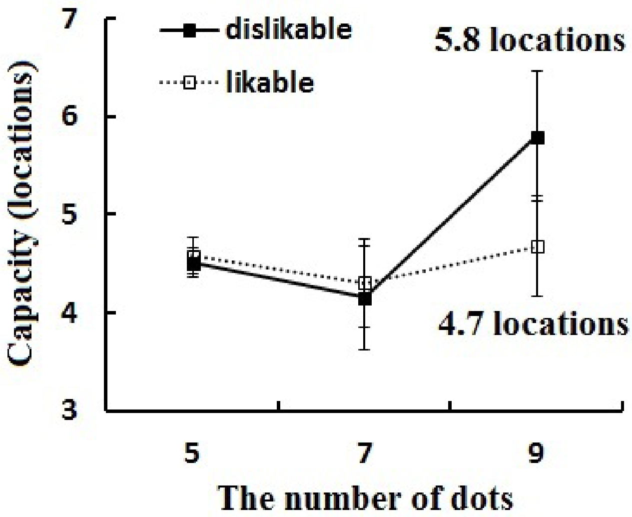


**Fig. 3** Mean capacity for VSTM of spatial locations classified by the visual-preference type in Experiment 1 ($n$ = 8). Error bars denote the standard errors of means.

## Experiment 2

### VSTM of Object Features Modulated by Visual Preference for Spatial Configurations

In Experiment 2, we examined whether visual preference for spatial configurations also affects VSTM for features embedded in objects. Given that VSTM for both location and object features are modulated by spatial configurations between objects (Jiang et al. 2000), we would expect that visual preference for spatial configurations also modulates not only spatial-location VSTM but also object-feature VSTM. Specifically, according to the results of Experiment 1, which indicated that the modulation of visual preference was observed when the number of objects was over the capacity limit of spatial-location VSTM (approximately seven locations: Franconeri et al. 2007), we would predict that the modulation of visual preference might be observed when the number of objects was over five, because the limited capacity of object-feature VSTM is approximately five objects (Alvarez & Cavanagh 2004; Luck & Vogel 1997). In order to examine this possibility, we used five-, seven-, and nine-line segments arrayed in the same spatial configurations used in Experiment 1.

Method

*Participants*

Eight new participants (age range: 19–27 years; three men and five women) were recruited from Tohoku University graduate and undergraduate students who were naive to the purpose of the experiment. They all had normal or corrected-to-normal visual acuity and provided informed consent before participating. The ethics committee of the Graduate School of Arts and Letters, Tohoku University, approved the study protocol.

*Stimuli*

Experiment 2 used a similar design to the one used in Experiment 1, except for the following changes: we used white line segments (degrees of visual angle were 0.6° × 1.4°, 64.0 cd/m$^2$) with three possible orientations (degrees of orientation were 0°, 45°, and 135°).

*Procedure*

The stimuli were presented in the same spatial configurations used in Experiment 1 within a 5 × 5 grid of imaginary cells subtending 7 × 7 degrees of visual angle on a black background (0.5 cd/m$^2$). At the beginning of the change-detection task (Figure 4), a fixation was presented for 500 ms at the center of the CRT monitor, followed by a memory display that contained several line segments for 600 ms. After this, a mask stimulus was presented for 100 ms, followed by a blank display for 900 ms, and then a test display containing several line segments appeared for 600 ms.[2] In half of the trials, the two displays were the same; in the other half of the trials, one of the line segments changed in the orientation. Then, a blank display was presented until participants responded. Participants were instructed to judge whether the orientations of all line segments were the same or the orientation of one line segment was different between the memory and test displays. Accuracy rather than speed was emphasized.

The participants each completed three blocks totaling 640 trials: 2 conditions (same or different) × 160 configurations (56, 40, and 64 configurations using five-, seven-, and nine-line segments, respectively) × 2 trials per configuration: the order of the number of line segments (five-, seven-, and nine-line segments) was counterbalanced across the participants. After the change-detection task, they were incidentally asked to rate their preferences for all 56 (five-line segments), 40 (7-line segments), and 64 (9-line segments) configurations presented at the center

[2] The reason for changing the presentation time from Experiment 1 to Experiment 2 was as follows: In Experiment 1, our preliminary investigation for the adjustment of experimental parameters showed higher accuracy when using the longer presentation time (e.g., 400 or 500 ms), which may indicate a ceiling effect. Thus, we adopted the shorter presentation time, such as 200 ms, in Experiment 1. In Experiment 2, preliminary investigation showed lower accuracy when using the shorter presentation time (e.g., 400 ms), which may indicate a floor effect. Thus, we adopted the longer presentation time of 600 ms in Experiment 2. These differential parameters may be consistent with previous findings that showed the differential capacity between spatial-location VSTM (approximately seven locations: Franconeri, Alvarez & Enns 2007) and object-feature VSTM (approximately five objects: Alvarez & Cavanagh 2004). These findings signify that the memory load for spatial-location VSTM is lower than that for object-feature VSTM, suggesting that Experiments 1 (investigating spatial-location VSTM) and 2 (investigating object-feature VSTM) require the shorter and longer presentation times, respectively.

of the display, as in Experiment 1; the ratings were given on a five-point scale from "very dislikable" (1) to "very likable" (5).

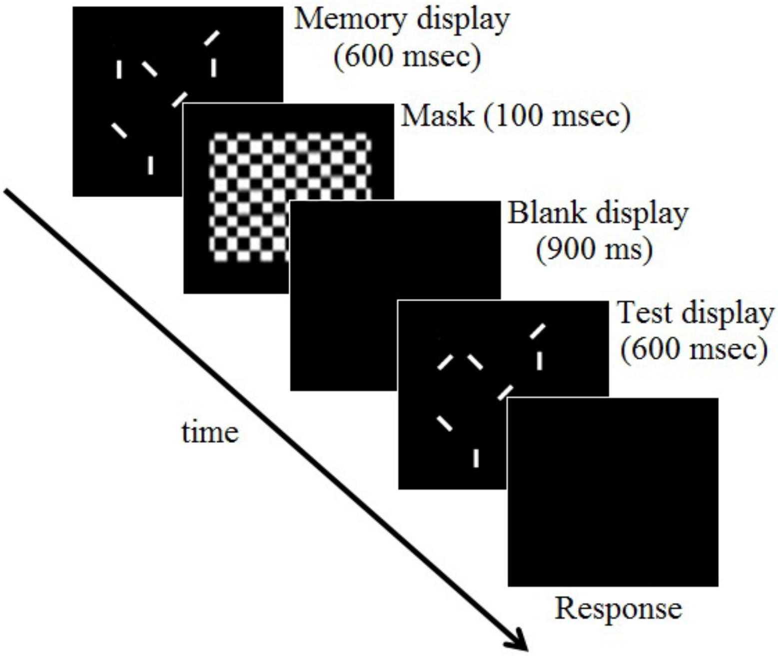


**Fig. 4** The change-detection task used in Experiment 2. The example shows the different condition when the number of line segments is 9, and the line segments are arrayed in the same locations of configurations in Figure 2 (b).

## Results & Discussion

We calculated the VSTM capacity (Cowan 2001) from the percentage of correct responses on the change-detection task for each condition based on the individual ratings, as in Experiment 1. Among the five-line segments, 39 % of the configurations were rated as dislikable and 33 % were rated as likable. For the seven-line segments, 41 % of the configurations were rated as dislikable and 36% were rated as likable. Among the nine-line segments, 35 % of the configurations were rated as dislikable and 37 % were rated as likable. These percentages were based on each participant's preference ratings. The classification criteria were identical to those used in Experiment 1. We confirmed that there were no significant differences in the proportions of dislikable and likable configurations between Experiments 1 and 2 by performing a three-way ANOVA with experiment (2: Experiments 1 or 2) as a between-participants factor and visual preference (2: dislikable or likable) and locations (3: five-, seven-, nine-dot locations) as within-participants factors [main effect of experiment: $F(1, 14)$ =

0.05, $p = .83$, $\eta_p^2 = 0.004$; main effect of visual preference: $F(1, 14) = 0.39$, $p = .54$, $\eta_p^2 = 0.03$; interaction between experiment and visual preference: $F(1, 14) = 0.15$, $p = .70$, $\eta_p^2 = 0.01$; interaction between experiment and locations: $F(2, 28) = 0.92$, $p = .41$, $\eta_p^2 = 0.06$; interaction between visual preference and locations: $F(2, 28) = 0.89$, $p = .42$, $\eta_p^2 = 0.06$; interaction between experiment, visual preference, and locations: $F(2, 28) = 0.51$, $p = .61$, $\eta_p^2 = 0.04$].

Figure 5 shows the mean VSTM capacity across all participants. We conducted a two-way repeated-measures ANOVA using visual preference and the number of line segments as within-participants factors. The results showed that there were main effects of visual preference and the number of line segments [visual preference: $F(1, 7) = 26.47$, $MSE = 0.14$, $p < .005$, $\eta_p^2 = 0.79$; the number of line segments: $F(2, 14) = 4.60$, $MSE = 0.83$, $p < .05$, $\eta_p^2 = 0.40$]. Moreover, there was a significant interaction between visual preference and the number of line segments [$F(2, 14) = 3.80$, $MSE = 0.20$, $p < .05$, $\eta_p^2 = 0.35$]. This interaction revealed a simple main effect of visual preference among seven- and nine-line segments [seven-line segments: $F(1, 21) = 19.29$, $MSE = 0.18$, $p < .001$, $\eta_p^2 = 0.48$; nine-line segments: $F(1, 21) = 9.27$, $MSE = 0.18$, $p < .01$, $\eta_p^2 = 0.31$]. The VSTM capacity for the line segments arrayed in dislikable configurations was larger than the capacity for those in likable ones among seven- and nine-line segments. Moreover, with regard to the simple main effect of the number of line segments, a significant difference was observed for the dislikable configurations [$F(2, 28) = 6.37$, $MSE = 0.52$, $p < .01$, $\eta_p^2 = 0.31$]. A post-hoc test (Tukey's HSD method) revealed that the VSTM capacity for the seven- and nine-line segments was larger than for the five-line segments [five- vs. seven-line segments: $t(28) = 2.33$, $p < .05$; five- vs. nine-line segments: $t(28) = 3.51$, $p < .05$; seven- vs. nine-line segments: $t(28) = 1.18$, $p = .24$]. In contrast, the simple main effect of the number of line segments was not significant for the likable configurations [$F(2, 28) = 2.52$, $MSE = 0.52$, $p = .099$, $\eta_p^2 = 0.15$].

One might argue that the categorization of dislikable and likable configurations was based on an arbitrary criterion, as in Experiment 1. In order to examine the relationship between the rating scores (1 to 5) and the capacity of VSTM, we conducted a single regression analysis using all data for seven- and nine-line segments in which the ANOVA results revealed significant effects. The analysis indicated a significant effect only for nine-line segments (adjusted $R^2 = .67$, $p < .05$) but not for seven-line segments (adjusted $R^2 = .21$, $p = .24$); for nine-line segments, the higher the rating scores, the smaller the capacity of VSTM. These results for nine-line segments were consistent with the ANOVA results. The results for seven-line segments were inconsistent with the ANOVA results; significant effects were observed only when treating visual preference as a nominal scale and not as a continuous scale. We speculated that rating scores might not disperse because the seven-dot configurations included only five patterns.

We also examined the effects of visual preference for spatial configurations on object-feature VSTM. The results showed that the VSTM capacity was larger when the line segments were arrayed in the dislikable configurations than in the likable configurations among seven- and nine-line segments. In addition, for the dislikable configurations, the VSTM capacity for the seven- and nine-line segments was superior to that for the five-line segments, suggesting that the superiority of dislikable configurations was observed when there were more than seven-line segments. Although, for the likable configurations, the VSTM capacity apparently increased in the nine-line segments condition, the VSTM capacity was the same across the five-, seven-, and nine-line segments conditions. These results indicate that visual preference for spatial configurations modulates object-feature VSTM, similar to spatial-location VSTM.

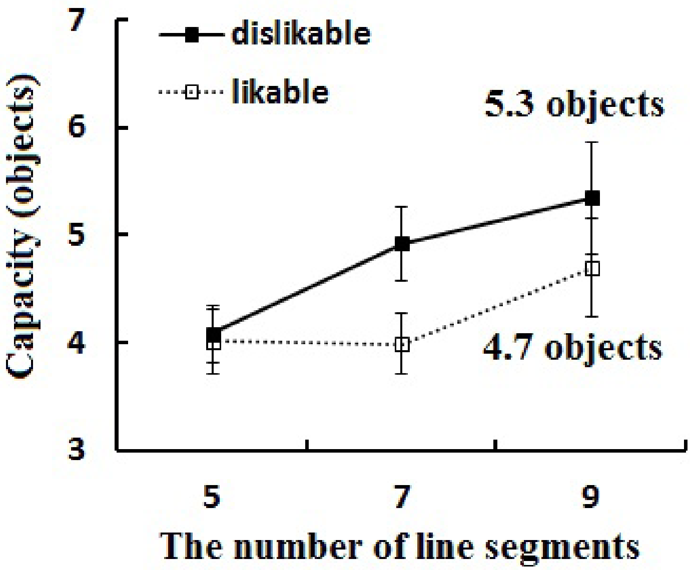


**Fig. 5.** Mean capacity for VSTM of object features classified by the visual-preference type in Experiment 2 ($n$ = 8). Error bars denote the standard errors of means.

## General Discussion

The purpose of the present study was to investigate whether visual preference for spatial configurations of objects could be one of several influential factors in VSTM. First, in Experiment 1, we examined whether visual preference for spatial configurations affected VSTM of spatial locations. We asked participants to memorize the locations of dots by using a same-different task. The results showed that the VSTM capacity for spatial locations was better for dislikable configurations than for likable ones when observers were asked to memorize the locations of nine dots. In contrast, these significant effects of visual preference on VSTM capacity were not observed in the five- and seven-dot locations. Furthermore, in order to reveal the significant effects of visual preference on VSTM in greater detail, we examined whether visual preference also affects VSTM of object-features (in particular, the orientation of line segments) in Experiment 2. We asked participants to memorize the orientation of line segments during a change-detection task. The results showed that the capacity of object-feature VSTM was larger when line segments were arrayed in dislikable configurations than in likable ones for seven- and nine-line segments. These findings offer support for our prediction that VSTM of both spatial locations and object features is better for dislikable spatial configurations than for likable ones.

One might argue that the mental load to memorize might arouse negative preference and potentially affect memory performance, instead of visual preference for dot configurations. In order to rule out this possibility, we measured visual preference levels for all spatial configurations used in the present experiments. The participants ($n$ = 10) were asked to rate their visual preferences for 160 spatial configurations used in the present experiments on a five-point scale ranging from "very dislikable" (1) to "very likable" (5), at their own pace. We conducted a repeated-measures ANOVA on the means of preference rating scores (Supplementary Figure 1). The results showed that there was no significant difference in preference rating scores among five-, seven-, and nine-dot configurations [$F(2, 18) = 0.39$, $p = .39$, $\eta_p^2 = 0.04$]. Therefore, the absolute visual-preference levels among five-, seven-, and nine-dot configurations were statistically equivalent; this means that the trends in visual preference for spatial configurations found in our experiments could not be explained by the possibility mentioned above.

Previous studies have indicated that VSTM mainly stores objects' spatial locations based on the global spatial configuration between objects (Alvarez & Oliva 2007; Jiang et al. 2000) and that the spatial regularity of the configuration is an important factor of VSTM representations (Alvarez & Oliva 2007). Our results extend these findings with a novel demonstration indicating that visual preference for the spatial configurations of objects can be regarded as a potent factor in spatial-location and object-feature VSTM representations.

The results of Experiment 1 showed that visual preference for spatial configurations modulated spatial-location VSTM for the nine-dot locations, but not for the five- and seven-dot locations. These findings may be related to the capacity limit of spatial-location VSTM (approximately seven locations; Franconeri et al., 2007). Namely, the superiority of the VSTM capacity for dislikable configurations could occur depending on whether or not the number of dots stored in VSTM exceeds the capacity limit of approximately seven locations. Moreover, visual preference for spatial configurations could also affect object-feature VSTM of seven- and nine-line segments that comprised the configurations, but not of five-line segments. Because previous studies have shown that the capacity limit of object-feature VSTM is approximately five objects (Alvarez & Cavanagh 2004; Luck & Vogel 1997), these results could be explained in terms of the capacity limit of object-feature VSTM. Thus, we could infer that the modulatory effect of dislikable configurations on object-feature VSTM might be observed when the number of line segments stored in VSTM exceeds the capacity limit of approximately five objects.

Previous studies (Jackson et al. 2009; Öhman, Flykt et al. 2001; Öhman, Lundqvist & Esteves 2001) have indicated that the visual system can effectively allocate visual attention, which is considered to be the gatekeeper for VSTM (e.g., Bundesen 1990), to threatening objects such as angry faces, snakes, or spiders. Öhman, Flykt, et al. (2001) demonstrated in a visual search task that search time was shorter when searching for threatening objects (such as snakes and spiders) among distractors that were neutral objects (such as flowers and mushrooms) than when searching for a neutral target among threatening distractors. Therefore, since previous studies (Jackson et al. 2009; Öhman, Flykt et al. 2001; Öhman, Lundqvist et al. 2001) have suggested that the critical factor for modulation of VSTM may be visual attention (which can be effectively captured by threat potential), it is highly likely that visual attention allocated to threatening objects might also enhance the encoding and storage of such objects in VSTM. In this respect, in our present study, we may infer that participants might allocate visual attention more effectively toward dislikable configurations than toward likable configurations, inducing the superiority of memory performance for dislikable configurations compared with that for likable ones. In order to adapt to the current environment, we need to form and store representations of dislikable configurations effectively, regardless of whether or not the capacity limit of VSTM is exceeded. When the number of objects presented exceeds the VSTM capacity, the VSTM system may need to temporarily enhance its capacity limit for dislikable configurations as a type of emergency reaction. This temporary memory enhancement seems to be ecologically meaningful (similar arguments were proposed by Haberkamp, Schmidt & Schmidt 2013).

One limitation of our present study is that we could not adequately explain the physical differences between the dislikable and likable configurations, because we only used individual ratings of visual preference (e.g., Bruce & McDonald 1993). Imamoglu (2000) showed that visual preference was greater when the complexity of visual stimuli was higher. This indicates that stimuli may be more pleasing when their complexity is at an optimal level of predictability. In contrast, simple stimuli may appear to be too predictable and hence boring. Moreover, even though visual preference or visual pleasure has been manipulated by changing the complexity (e.g., Amir et al. 2011; Biederman & Vessel 2006; Markovic 2012; Yue, Vessel & Biederman 2007), individual differences that cannot be ignored have been observed in the preference ratings. Therefore, in our present study, we controlled complexity by maintaining ESS (i.e., we used only ESS 8 configurations), and we revealed the effects of visual preference on the VSTM capacity by using the individual ratings.

In relation to the above explanations, a further possibility might exist in which visual preference might vary depending on the complexity of each pattern included in ESS 8 subsets: We could examine the correlation between pattern goodness (or complexity) and pattern preference rating scores for individual patterns in subsets of ESS 8. Lachmann & Geissler (2002) indicated the differences for cognitive performance (using response time) between each ESS 8 pattern. Even if these were the same ESS 8 subsets, there would be a difference in individual pattern goodness and their cognitive performance with these patterns. Considering previous findings (Imamoglu 2000), which showed the relationship between pattern goodness (or complexity) and pattern preference, we assumed the possibility that individual pattern preference was related to individual pattern goodness in subsets of ESS 8. In order to examine this possibility, we conducted a correlation analysis between pattern goodness and pattern preference rating scores. We used previous goodness rating scores from Lachmann & Geissler (2002) and Garner & Clement (1963) and preference rating scores from Takahashi et al. (2012) (whose detailed data are not shown in their paper). The results indicated that there were no significant correlations between pattern goodness and pattern preference rating scores [goodness from Lachmann & Geissler and preference from Takahashi et al.: $r$ = -.61, $p$ = .15; goodness from Garner & Clement and preference from Takahashi et al.: $r$ = -.50, $p$ = .25]. These results indicated that individual pattern goodness and individual pattern preference might be distinct factors in subsets of ESS 8. Since the stimuli used in our present study were only ESS 8 subsets (i.e., we used only poor patterns in terms of goodness), the results were consistent with those predicted by Garner's hypothesis and might be natural results. In addition to Garner's ESS hypothesis, using the rotation and reflection transformation principle, the factor of pattern preference may exist with controlled subsets of ESS.

In conclusion, the present research demonstrated that visual preference of spatial configurations modulates the capacity of spatial-location and object-feature VSTM. While the modulatory effect of visual preference on spatial-location VSTM was observed only for nine-dot configurations, this effect on object-feature VSTM was observed for more than seven-line segments. The difference can be explained in terms of differences in capacity between spatial-location VSTM and object-feature VSTM. The present results provide evidence that visual preference of configurations plays an important role in determining the capacity of VSTM, and suggest that the occurrence of the effect does not only depend on the number, but also the contents of objects to be stored in VSTM.


## Summary

We examined the effects of visual preference for configurations of objects on visual short-term memory (VSTM) of spatial locations (Experiment 1) and object features (Experiment 2) using a same-different (Experiment 1) and a change-detection (Experiment 2) task. In Experiment 1, participants judged whether the locations of five, seven, and nine dots were the same or different in two successive displays. In Experiment 2, participants judged whether the orientations of line segments were the same or different in two successive displays comprising five-, seven-, or nine-line segments arrayed in the same configurations used in Experiment 1. After these memory tasks, participants were incidentally asked to rate visual preference for the configurations on a five-point scale. Results showed that memory performance for dot locations arrayed in dislikable configurations was better than for those arrayed in likable configurations in nine-dot conditions (Experiment 1). This pattern of results was replicated in VSTM of object features in seven- and nine-line segments conditions (Experiment 2). These results suggest that the effects of visual preference are determined by the differences in capacity limits between spatial-location VSTM (approximately 7 locations) and object-feature VSTM (approximately 5 objects). Thus, the effects may be observed when the number of the locations or objects presented in the display exceeds the limit of each capacity.

**Keywords**: Visual short-term memory, Visual preference, Spatial configuration.


## Zusammenfassung

Wir untersuchten die Wirkung von visuellen Vorlieben für Anordnungen von Objekten auf das visuelle Kurzzeitgedächtnis (VSTM) mit Hilfe von räumlichen Positionen (Experiment 1) und Objektmerkmalen (Experiment 2) mit einer gleich- unterschiedlich (Experiment 1) und einer Wechsel-Feststellungs-Aufgabenstellung (Experiment 2). In Experiment 1 beurteilten die Versuchspersonen, ob die Lage von fünf, sieben und neun Punkten in zwei aufeinanderfolgenden Anzeigen dieselbe war oder ob es Unterschiede gab. In Experiment 2 beurteilten die Teilnehmer, ob die Ausrichtung von Liniensegmenten zwischen zwei aufeinanderfolgenden Anzeigen gleich oder unterschiedlich war. Diese Segmente bestanden aus Fünf-, Sieben- oder Neun-Linien-Segmenten in denselben Anordnungen wie in Experiment 1. Nach diesen Erinnerungsaufgaben wurden die Teilnehmer beiläufig gebeten, visuelle Präferenzen für die Anordnungen auf einer fünfstufigen Skala zu bewerten. Die Ergebnisse zeigten, dass die Gedächtnisleistung für die Lage der Punkte in unbeliebten Anordnungen besser war als für die neun-Punkte-Stellungen in beliebten Anordnungen (Experiment 1). Dieses Ergebniss-Muster wurde in VSTM von Objektmerkmalen unter den Bedingungen von Sieben- und Neun-Linien-Segmenten wiederholt (Experiment 2). Diese Ergebnisse legen nahe, dass die Wirkungen der visuellen Vorlieben durch Unterschiede der Kapazitätsgrenzen zwischen dem räumlichen Standort VSTM (ca. 7 Stellen) und der Objekt-Funktion VSTM (ca. 5 Objekte) bestimmt werden. Somit können die Wirkungen beobachtet werden, wenn

die Anzahl der in der Anzeige präsentierten Positionen oder Objekte die Grenze der einzelnen Kapazität übersteigt.
Schlüsselwörter: Visuelles Kurzzeitgedächtnis, visuelle Vorlieben, Raumkonfiguration.

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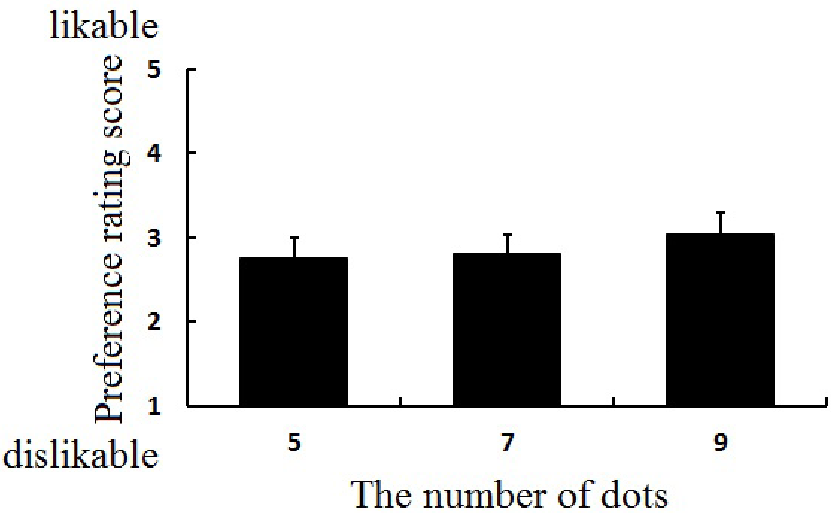


**Supplementary Figure 1** The scores of visual-preference rating in the control experiment ($n$ = 10). Error bars denote the standard errors of means.

**Junichi Takahashi** (Corresponding author), born in 1983, has been an Assistant Professor at the Faculty of Human Development and Culture, Fukushima University, Japan. He received his Ph. D. from Tohoku University. Research interests are in perceptual characteristics in children with developmental disorders.
**Address:** Department of Human Development, Faculty of Human Development and Culture, Fukushima University, 1 Kanayagawa, Fukushima-shi, Fukushima 960-1296, Japan.
E-mail: j-takahashi@educ.fukushima-u.ac.jp

**Yousuke Kawachi,** born in 1979, has been a lecturer at Kansei Fukushi Research Institute, Tohoku Fukushi University, Japan. He received his Ph. D. from Tohoku University. Research interests are in how sensory information within vision and across sensory modalities is integrated into an event representation.
**Address:** Kansei Fukushi Research Institute, Tohoku Fukushi University, 6-149-1, Kunimigaoka, Aoba-ku, Sendai, Miyagi 989-3201, Japan.
Email: yousuke.kawachi@gmail.com

**Jiro Gyoba,** born in 1954, has been a Professor at the Graduate School of Arts and Letters, Tohoku University, Japan. He received his Ph. D. from Tohoku University. Research interests are in psychology of visual cognition, aesthetic perception, and human information processing.
**Addresses:** Department of Psychology, Graduate School of Arts and Letters, Tohoku University, 27-1, Kawauchi, Aoba-ku, Sendai, Miyagi 980-8576, Japan.
Email: gyoba@m.tohoku.ac.jp