Research Report

Configural and analytical processing of familiar and unfamiliar objects

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Accepted 15 February 2005
Available online 31 March 2005

Abstract

Configural processing could develop for non-face visual objects as one becomes familiar with those objects through repeated exposure. To explore the role of familiarity in object recognition, we studied the effect of adaptation to a visual object (adapting stimulus) on the identification performance of other objects (test stimulus) while adapting and test stimuli were exactly the same, shared parts or were completely different. We used a subset of English alphabets (p, q, d and b) as familiar objects and an unfamiliar set of symbols constructed from same parts but with different configurations. Adaptation to a member of each set led to a lower identification performance for that object in a crowding paradigm. Adaptation to each member of the unfamiliar set resulted in decreased identification performance for the same object and those members of the set that shared parts with the adapting stimulus. But no such transfer of adaptation was observed for the familiar set. Our results support the notion that processing of object parts plays an important role in the recognition of unfamiliar objects while recognition of familiar objects is mainly based on configural processing mechanisms.

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Theme: Sensory systems
Topic: Visual psychophysics and behavior

Keywords: Configural processing; Face recognition; Identification performance

1. Introduction

Recognition of faces using configural or part-based processing has been studied widely [19]. The term “configural processing” has been used with different meanings by different authors and refers to at least three different processes in the face recognition literature: (1) sensitivity to first-order relations like the existence of two eyes and a nose above a mouth. Congruent with this definition, dramatic decreases in behavioral performance [19] and brain activation [14] due to face inversion have been shown; (2) sensitivity to second-order relations such as distance among parts of a face [5]; (3) holistic processing where face is processed as a whole or a gestalt [25]. The common notion in these reports is that configural processing refers to any process that takes into account the spatial relations of features of an object (first-order relational processing). It is contrasted with part-based processing which is also called featural or analytical processing.

Recently, Baker et al. [3] investigated the effect of training discrimination of unfamiliar objects on the response properties of the macaque inferotemporal neurons. They reported that some inferotemporal neurons were engaged in a configural process for trained objects while contributing to the coding of another untrained set of unfamiliar objects in a part-based manner. They proposed that purely configural and analytical processing of visual objects are the two extremes of a singular continuum and the selection of a processing strategy for each object is a consequence of the degree of familiarity with that object [4]. This conjecture is in line with the results of other studies arguing for more involvement of configural processing of visual objects in
people who were experts in recognition of non-face stimuli [10]. Converging evidence from psychophysical [6], ERP [21] and neuroimaging studies [7,8] has emerged.

The notion that first-order relational processing is unique for faces has received major objections. For example, it has been shown that first-order relational processes for other categories of visual objects may occur as the objects become familiar [3]. Structural theories of object recognition assume faces to be a special case of visual objects and treat other objects with structural descriptions. Emergence of first-order relational processing for other object categories as a result of factors such as familiarity would challenge these theories. In this study, we investigated first-order relational processing of letters in comparison with an unfamiliar set of stimuli.

Lack of a general consensus on a definition for object “parts” and what determines the complexity of objects in a visual image constrains attempts to compare the degree of holistic processing for familiar vs. unfamiliar visual objects. Any such comparison would only be valid if familiar and unfamiliar objects were composed of the same parts.

Using adaptation to tap various mental or neural process has a long history in the cognitive sciences [15]. Lack of a good definition for shape space has restricted the use of adaptation to investigate the processes involved in visual object recognition. But some recent studies have demonstrated the effects of adaptation in face recognition [16,24].

Assuming that common components are processed by common processing units, here we used two sets of visual objects made from a common set of components. One set with a familiar configuration of components and the other set with an unfamiliar arrangement. Adaptation to familiar objects should lead to decreased accuracy in identification of that object but not any other configuration of the same parts provided that a first-order relational processing is used.

2. Methods

2.1. Stimuli

Two sets of familiar and unfamiliar stimuli (Fig. 1a, b) were constructed from a set of three simple segments (Fig. 1c). The familiar stimuli consisted of letters b, d, p and q and the unfamiliar set consisted of artificial stimuli made up from components of the same letters (Fig. 1b). Within each set, any two members could have one of three possible relations: (1) same part stimuli: constructed from same parts but in different configurations (Fig. 2b); (2) different part stimuli type I: constructed from different components with same relative configuration (Fig. 2c); (3) different part stimuli type II: constructed from different components in a different configuration (Fig. 2d). As shown in Fig. 2b and c, our “different part” stimuli have a common part (a vertical bar) and a non-common part (c shape curve) that make them different.

2.2. Experimental paradigm

In the first experiment (non-adapted condition), target stimulus was presented in the middle of an array of five stimuli. This array was presented at 12° above a fixation point. In each trial, any of these five stimuli were selected randomly from members of one of stimuli sets (familiar or unfamiliar). Each stimulus subtended 0.75° × 0.50° of visual field and was placed 0.25° apart from neighboring stimuli. Array of stimuli were presented for 100 ms. Subjects were instructed to maintain fixation and identify the stimulus located at the center of the stimuli array by pressing one of four keys on the computer keyboard. They were asked to report their best guess even if they could not recognize the central stimulus. Instructions were given before each session. Experiments were performed in a dimly lit room. Each subject sat through a total number of 400 trials.

In the second experiment (adapted condition), an adaptation phase preceded the identification task. In this adaptation phase, a grid of 750 stimuli, each 0.75° × 0.50° in size, were presented for 60 s. Subjects were asked to maintain fixation

<table>
<thead>
<tr>
<th>Familiar Set</th>
<th>Unfamiliar set</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. b b</td>
<td>k k</td>
</tr>
<tr>
<td>b. b p</td>
<td>k p</td>
</tr>
<tr>
<td>c. b d</td>
<td>k d</td>
</tr>
<tr>
<td>d. b q</td>
<td>k q</td>
</tr>
</tbody>
</table>

Fig. 2. Relationship between stimulus “b” and the other members of the familiar set and an exemplar similar relation between members of the unfamiliar set: (a) Same stimulus; (b) same parts but with different configuration; (c) different parts I; (d) different parts II.

Fig. 1. Stimuli set. (a) Familiar set, (b) unfamiliar set, (c) three simple shapes used to construct the stimulus set.
on a spirally moving fixation point to prevent retinal adaptation. Subjects went through the same identification paradigm as experiment I after the adaptation phase. Adaptation reinforcement was provided once every five trials by presenting the adaptation grid for 5 s. Adapting and test stimuli were selected from the same set (e.g. b as adapting and p as test from familiar set). Adapting stimulus and target stimulus had one of four possible relations (e.g. “same parts” for relation between b and p) as depicted in Fig. 2 and also previously described in Section 2.1 (Fig. 3).

2.3. Stimulus presentation apparatus

All stimuli were displayed on a 15” Hansol 510P computer display with vertical refresh rate of 85 Hz controlled by an NVIDIA TNT2 64 MByte graphic adapter and viewed from a distance of 57 cm. Presentation® software (version 0.55) was used to implement the experimental paradigm.

2.4. Subjects

Seven male university students participated in this study; two of them were authors (BN and MA) and other subjects were naive with regard to the purpose of the study. All subjects had normal or corrected-to-normal visual acuity.

3. Results

Performance of all subjects in the non-adapted condition was well above chance (chance level = 25%). We compared performance of all subjects in the adapted and non-adapted conditions using paired t test. To compare the performance for each subject, we used Chi-square test. In order to assess subject variability, we used two-way ANOVA to determine whether the observed effects are consistent over all subjects or not. Performance for each condition is reported as mean ± standard error throughout the Results section and significance level is set at $P < 0.05$. Details of performance of all subjects in each condition are shown in Table 1.

3.1. Adaptation to a stimulus leads to lower identification performance for same stimulus in both familiar and unfamiliar sets

a. The effect of adaptation to a familiar stimulus on the identification performance for the same stimulus: Subjects’ performances in adapted conditions (0.25 ± 0.03) comparing to non-adapted conditions (0.62 ± 0.04) are decreased. Paired t test shows significant difference

Table 1

<p>| Identification performance of subjects for detection of stimuli in adapted and non adapted conditions |
|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|</p>
<table>
<thead>
<tr>
<th>Adapted to</th>
<th>Identification of</th>
<th>Identification performance</th>
<th>Aggregated value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. adaptation</td>
<td>After adaptation</td>
<td>P value</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Same stimulus</td>
<td>b</td>
<td>b</td>
<td>0.64 ± 0.04</td>
</tr>
<tr>
<td>Same parts</td>
<td>q</td>
<td>q</td>
<td>0.60 ± 0.08</td>
</tr>
<tr>
<td>Different part I</td>
<td>b</td>
<td>d</td>
<td>0.61 ± 0.05</td>
</tr>
<tr>
<td>Different part II</td>
<td>q</td>
<td>p</td>
<td>0.68 ± 0.03</td>
</tr>
<tr>
<td>Same stimulus</td>
<td>d</td>
<td>d</td>
<td>0.67 ± 0.04</td>
</tr>
<tr>
<td>Same parts</td>
<td>f</td>
<td>f</td>
<td>0.73 ± 0.06</td>
</tr>
<tr>
<td>Different part I</td>
<td>d</td>
<td>e</td>
<td>0.59 ± 0.02</td>
</tr>
<tr>
<td>Different part II</td>
<td>d</td>
<td>e</td>
<td>0.72 ± 0.05</td>
</tr>
</tbody>
</table>

In different blocks of experiment, different stimuli are used and aggregated.
between these two conditions ($P = 0.000$). All subjects showed the similar effect individually ($P < 0.05$, Chi-square test).

b. The effect of adaptation to an unfamiliar stimulus on the identification performance for the same stimulus: Adaptation effect was not a function of familiarity; similar to familiar stimuli, identification performance declined significantly ($P = 0.000$) following adaptation to the same unfamiliar stimuli ($0.38 \pm 0.06$) comparing to non-adapted condition ($0.70 \pm 0.03$). All subjects showed the similar effect ($P < 0.05$, Chi-square test).

3.2. The effect of adaptation to a stimulus on the identification of stimuli with same parts is different for familiar and unfamiliar object sets

The effect of adaptation to a familiar stimulus on the identification performance for the stimuli with the same part: The difference between identification performance in non-adapted ($0.65 \pm 0.03$) and adapted trials ($0.67 \pm 0.02$) for familiar set when adapting stimulus and the target were composed from the same parts was not significant ($P = 0.442$). Each one of the subjects showed similar effect ($P > 0.05$, Chi-square test).

The effect of adaptation to an unfamiliar stimulus on the identification performance for the stimuli with the same part: Following adaptation, subjects were significantly worse at detecting an unfamiliar stimulus that shared parts with the adaptation stimulus. The difference between identification performance in non-adapted ($0.66 \pm 0.03$) and adapted trials ($0.42 \pm 0.03$) for familiar set when adapting stimulus and the target were composed from the same parts was significant ($P = 0.000$). Each one of the subjects showed similar effect ($P < 0.05$, Chi-square test).

Although no significant difference was seen in performance of the subjects for identification of familiar and unfamiliar stimuli in non-adapted trials ($P = 0.796$), their performance for the members of the two sets showed significant difference after adaptation to stimuli with the same parts ($P = 0.000$).

3.3. Adaptation to a stimulus had no significant effect on identification performance for other members of the two sets

There was no significant difference in identification performances between non-adapted condition and when subjects were adapted to a stimulus with different parts (c and d in Fig. 2). This was the case for both familiar and unfamiliar sets ($P > 0.05$).

3.4. Adaptation index

In order to determine the effect of adaptation to stimulus A in the identification performance for stimulus B, we quantified the extent of the effect of adaptation to one stimulus (A) on identification performance of the other stimulus (B) by calculating an adaptation index:

Adaptation index ($A, B$) = ($P_n(B) - P_a(A, B)$)/$P_n(B)$

Where, $P_n(B)$ = Identification performance for stimulus B in non-adapted condition, $P_a(A, B)$ = Identification performance for identification of stimulus B following adaptation to stimulus A.

This index is indicative of the effect of adaptation to a stimulus on identification performance of other stimuli. So, the higher the adaptation index the stronger effect of adaptation is.

Adaptation indices for different members of familiar and unfamiliar set are plotted in Fig. 4. There is a significant difference between adaptability index for adaptation with “same part” stimuli in familiar and unfamiliar sets ($P = 0.000$). Furthermore, there is a significant difference between the effect of adaptation to “same” stimuli in familiar and unfamiliar sets ($P = 0.001$).

3.5. Subject variability

Two-way ANOVA shows that main findings of this study were independent from variations of subjects’ performance. There was no interaction between the subjects variability and the decrease of performance due to adaptation to the same part unfamiliar stimuli, lack of this...
effect in familiar set and the effect of performance decrease due to adaptation with same stimuli in familiar and unfamiliar set ($P > 0.01$).

4. Discussion

We showed that adaptation to an unfamiliar visual stimulus not only decreases the identification performance for that object, but also decreases the performance in identification of other stimuli that shared similar parts with the original stimulus. We also demonstrated that, for letters, which are highly familiar visual objects [20], no such transfer of adaptation is observed. Therefore, our results indicate that, when faced with a familiar object, the visual system employs strategies that prevent the transfer of adaptation between different configurations of the same parts. On the other hand, in the case of unfamiliar objects, adaptation to a set of object parts is not restricted to that object’s specific configuration. This result is congruent with previous psychophysical [10,21] and electrophysiological [4] reports of increasing configural processing for visual objects with increasing familiarity. We interpreted this difference of the effect of adaptation as a consequence of different degrees of familiarity between two sets but there remains a possibility for contribution of other uncontrolled low level differences such as existence of closed curves in letters and open curves in the unfamiliar set.

Our subjects assigned verbal labels to members of unfamiliar stimuli. However, it is possible that our finding is due to different semantic priming for letters than for the other set as verbal labels for letters were more familiar and practiced than the verbal labels for unfamiliar set.

Although there is a debate for configural processing of words, there is an agreement between researchers on configural processing of letters in literate individuals [20]. However, whether letter processing mechanisms use the same resources involved in processing other visual objects or not is still not clear [22].

Our results show that units involved in representation of letters are not influenced by other letters with similar parts. Considering that part-sensitive units do exist and that they might be involved in the representation of unfamiliar objects used in the current study, our findings suggest a dissociation of letter processing mechanisms from those involved in processing other objects.

Letters and a few other categories of visual objects have been reported to selectively activate focal regions of the cerebral cortex. These categories include faces [2,18], houses [1,12], letters and letter strings [17]. In addition, adaptation to letters has been shown to decrease activation in the left fusiform area [9]. However, such focal activation in response to letters does not necessarily imply a modular organization for letter processing [11,17] simply because letters are highly similar visual stimuli and are therefore expected to activate adjacent cortical regions without necessarily involving the activation of the same modules.

There is an unresolved debate about emergence of selective processing modules for letters as there might be for some other familiar objects. Josef and colleagues [13] showed selective activation of inferior parietal cortex in response to visual presentation of letters which might be a possible candidate for letter processing module.

Based on their neuroimaging findings, Steingrimsson and colleagues [23] argued against the presence of a specific region for identifying letters (compared to other less familiar objects). In line with the notion of dissociation between mechanisms involved in letter processing and recognition of other visual objects, our data are congruent with the existence of specific modules for processing letters in a manner different from that of other visual objects; a more configural processing of their parts is plausible. But the possibility of recruiting other common regions, such as fusiform gyrus as suggested by Steingrimsson [23], is still tenable.

Acknowledgment

We wish to thank Dr. Bahador Bahrami for his comments on the manuscript.

References


