Holistic Processing Is Not Always a Property of Right Hemisphere Processing- Evidence from Computational Modeling of Face Recognition

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Abstract. The hemispheric asymmetry literature traditionally posits that holistic processing (HP) is a property of right hemisphere (RH) processing. Nevertheless, a counterexample was recently found: for Chinese character recognition expertise, studies showed reduced HP (as measured in the composite task) and increased RH lateralization, revealing that these two effects may be separate processes. With a computational model of face recognition, in which we implement a theory of hemispheric asymmetry in perception that posits a low spatial frequency bias in the RH and a high spatial frequency bias in the left hemisphere (i.e., the Double Filtering by Frequency Theory of Ivry and Robertson), here we show that when the face recognition task relies purely on featural information, there is a negative correlation between HP and RH lateralization: HP increases whereas RH lateralization decreases with increasing stimulus dissimilarity. In contrast, when the face recognition task relies purely on configural information, there is a strong positive correlation between HP and RH lateralization: both HP and RH lateralization increase with increasing stimulus dissimilarity. These results suggest that HP and RH lateralization are separate processes that can be influenced differentially by task requirements.

Keywords: Holistic processing, hemispheric lateralization, face processing, connectionist modeling.

1 Introduction

Holistic processing (HP) of faces refers to the phenomenon of viewing faces as a whole instead of a set of parts. This HP effect is thought be a marker of human expertise in face processing [1]. In addition to the HP effect, face processing has been shown to involve right hemisphere (RH) lateralization, as indicated by the left side bias (LSB) effect: a chimeric face made from two left half faces from the viewer's perspective is usually judged more similar to the original face than one made from two right half faces [2,3]. In addition, fMRI studies show that an area inside the fusiform gyrus (*fusiform face area*) responds selectively to faces with larger activation in the RH than the left hemisphere (LH) [4]; ERP data also show that faces elicit larger N170 than other types of objects, especially in the RH [5].

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The HP effect has been shown to be linked to brain activation in face selective areas especially in the RH [6,7]. It has also been shown that the increase in HP after artificial object recognition training is correlated with right fusiform area activity [8]. These results are consistent with the hemispheric asymmetry literature that posits a holistic/analytic dichotomy between RH and LH processing [9], and suggest that HP and RH lateralization would go together. Nevertheless, a counterexample was recently found: Chinese character recognition experts have reduced HP and increased RH lateralization in processing Chinese characters compared with novices [10]. This effect suggests that holistic processing and RH lateralization may be separate processes that do not always go together.

Faces and Chinese characters differ in both featural and configural dimensions. In the featural dimension, faces consist of common features (i.e., the eyes, nose, and mouth) and the features of different faces usually look similar to each other; in contrast, Chinese character recognition involves discriminating different combinations of more than two hundred basic stroke patterns [11], which usually look dissimilar to each other. In the configural dimension, second-order spatial relations (i.e., distances) between face components have been shown to be more important in face recognition than in the recognition of other visual object classes [12], whereas this configural information is not important in Chinese character recognition, since changes in distance among character components do not change the character identity [13]. The difference between face and Chinese character recognition in their reliance on configural and featural information may explain the different relationships between HP and RH lateralization that were found between them. We hypothesize that HP and RH lateralization do not always go together, and it depends on the task requirements in either the featural or the configural dimension. We test this hypothesis by using faces that differ purely in configuration or purely in features in a face recognition task. We adopt a computational modeling approach. We introduce our model below.

2 Modeling

2.1 Hemispheric Processing Model

The model (Figure 1) is an instance of the intermediate convergence model of face recognition [14]. This model uses Gabor responses over the input images to simulate neural responses of cells in the early visual area, and Principal Component Analysis (PCA) to simulate possible information extraction processes beyond the early visual area. This PCA representation is then fed as the input to a two-layer feed-forward neural network. In addition, the model implements a theory of hemispheric asymmetry in perception, Double Filtering by Frequency theory (DFF) [15]. The theory posits that visual information coming into the brain goes through two frequency-filtering stages. The first stage involves attentional selection of a task-relevant frequency range. At the second stage, the LH amplifies high spatial frequency (HSF) information, while the RH amplifies low spatial frequency (LSF) information. For the second stage, we implemented two conditions. In the DFF condition (see Fig.1), the differential frequency bias in the two hemispheres is implemented by using two sigmoid functions assigning different weights to the Gabor responses in the two hemispheres. In the baseline condition, we set all weights to the Gabor responses to 1 so that there is no differential frequency bias between the two hemispheres.

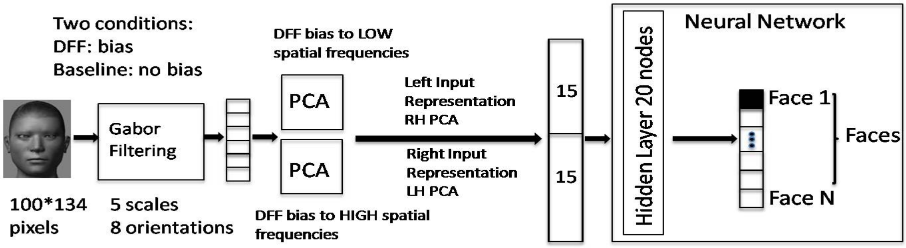

Fig. 1. Model of face recognition implementing a theory of hemispheric asymmetry in perception, the Double Filtering by Frequency (DFF) theory

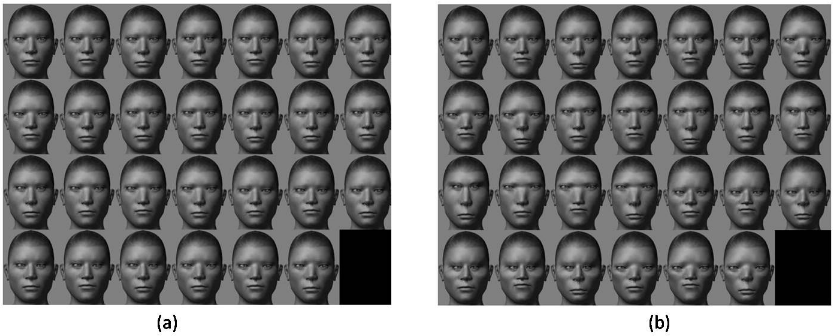

Fig. 2. Configural datasets. (a) baseline spacing of facial features, (b) increased spacing of facial features.

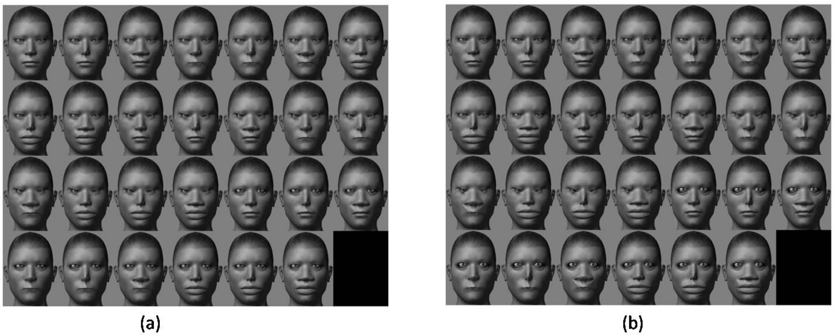

Fig. 3. Featural datasets. (a) baseline aspect of features, (b) aspect of features with increased magnitudes of changes compared to the baseline.

2.2 Configural vs. Featural Recognition Tasks

In a configural recognition task, all faces have the same eyes, nose, and mouth, but their configurations differ. In contrast, in a featural recognition task, all faces have the same configuration but the features differ in their aspects.

In order to investigate the relationship between HP and RH lateralization when the recognition tasks depend on either configural or featural information, we created both configural and featural face datasets in a controlled manner comparably to [16]. Face images of photorealistic human characters were created with the MakeHuman software [17]. We customized a default Asian face model to produce all the faces. While keeping all facial features (i.e., eyes, nose, and mouth) identical, we changed the size of the spacing between eyes and moved up or down eyes and mouth to create the 27 faces of the two configural sets (Figure 2). Figure 2a and 2b respectively shows the baseline configural set and the increased spacing (IS) dataset. Namely, faces in Figure 2b were made of bigger spacing between features than the faces in Figure 2a. Hence, faces in the IS dataset are more dissimilar to one another than faces in the baseline set. Having two datasets allowed us to examine the effect of stimulus similarity on HP and RH lateralization. In contrast, by changing the aspects of the mouth, the nose, and the eyes but without changing the locations of these features, we created the 27 faces of the featural sets (Figure 3). Figure 3a shows the baseline featural set. Faces in Figure 3b were obtained through bigger magnitudes in the changes of the aspects of the features. Consequently, faces in Figure 3b dataset are more dissimilar to one another than faces in the baseline set.

For each dataset in Figures 2 and 3, we created 10 new training datasets by randomly sampling without replacement 20 faces out of the total of 27 faces. The 10 corresponding testing datasets were derived by rendering each image slightly darker by multiplication by a scaling factor of 0.9. We used these datasets to examine how different recognition task requirements (configural vs. featural) modulate the relationship between the HP and RH lateralization effects. In both tasks, the model in Figure 1 was trained to recognize the stimuli in the corresponding dataset.

2.3 Modeling of the Composite Task and Measure of Holistic Processing

In human studies, HP is usually assessed through the composite paradigm [18]. We implemented the *complete* variant of the composite paradigm because of its robustness [18]. In this paradigm, two stimuli are presented briefly for example simultaneously. Participants attend to either the top or bottom halves of the stimuli and judge whether they are the same or different (see Figure 4). In congruent trials, the attended and irrelevant halves lead to the same response, whereas in incongruent trials, they lead to different responses. HP is indicated by interference from the irrelevant halves in matching the attended halves; it can be assessed by the performance difference between the congruent and the incongruent trials.

In face processing, the HP has been accounted for by computational models [19,20]. To assess HP in our model, we applied the method used by [21] which was inspired by [20]. Namely, after training we attenuated the Gabor responses of either the top or bottom half of the images in the test set by multiplying a factor of 0.125 to simulate directing the models' attention to the bottom or top half of the images respectively. We created 4 types of stimulus pairs corresponding to the 4 conditions in Figure 4 (see an example in Figure 5a). For each simulation, a different set of twenty pairs of images in each condition was randomly drawn to form the materials (80 pairs in total). We calculated the correlation of the hidden layer representations in each pair as the similarity measure between them. A threshold was set to be the midpoint between the mean correlation of the "same" stimulus pairs and that of the "different" stimulus pairs. We assumed that the model responded "same" when the correlation of a pair was higher than the threshold, and responded "different" when the correlation was lower than the threshold. The HP effect was indicated by the discrimination performance difference between the congruent and incongruent trials measured by d'.

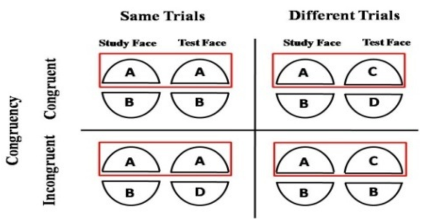

Fig. 4. Design of the composite task, with top halves attended

Fig. 5. (a) Illustrative example of a Congruent Same pair for the composite task where bottom half is attenuated. (b) Example of a left-lateralized stimulus for measuring lateralization effects.

2.4 Measuring Hemispheric Lateralization Effect

The left side (RH) bias was assessed by the accuracy difference between recognizing a left-lateralized stimulus (carrying RH/LSF information; see Figure 5b) as the original stimulus and recognizing a right-lateralized stimulus (carrying LH/HSF information) as the original one. We defined RH lateralization (RH/LSF preference, [14]) as the left side bias measured in the biased condition minus that measured in the baseline condition.

2.5 Modeling Details

In the present implementation, the face input (100 x 134 pixels) was first filtered with a grid (6 x 6) of overlapping 2D Gabor filters in quadrature pairs at five scales and eight orientations. The five scales corresponded to 2 to 32 cycles per face. The resulting Gabor vector representation of the face was split into left and right halves. The perceptual representation of each half was compressed into a 15-element representation using PCA. After PCA, each principal component was z-scored to equalize the contribution of each component in the model. The PCA representation was then fed to a feed-forward network with one hidden layer of 20 nodes. The number of nodes was determined empirically to allow efficient training of the network. The output layer of the neural network had one output for each of the 20 faces of the testing set. The neural network was trained with gradient descent with adaptive learning rate backpropagation from the MATLAB® Neural Network Toolbox (Version 7.0.3). The network was trained for both 400 epochs and 150 epochs. 400 epochs was enough for all the models to reach almost perfect recognition rates on both training and testing sets (accuracy ~ 99%). However, we found a strong ceiling effect for the configural task on the baseline datasets: recognition rates for both left-lateralized stimuli and right-lateralized stimuli were very high (~ 98%) and so close that the size of RH lateralization effect was on average less than 1%. Training with only 150 epochs put an end to the ceiling effects while maintaining high recognition rates (accuracy ~ 90% for both training and testing sets). We thereafter reported results for simulations with a training of 150 epochs.

For each of the featural and configural task, we trained the model with the 20 different datasets. Hence, we collected for each task 20 data points of RH lateralization to plot against 20 data points of holistic Δd' (Congruent d' – Incongruent d'). We then tested for any correlation between RH lateralization and HP.

3 Results

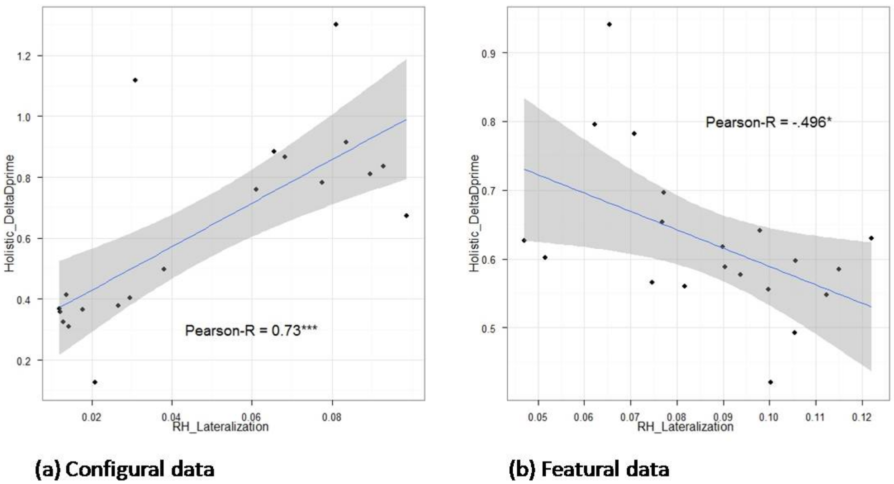

Fig. 6. Holistic Δd' plotted against RH lateralization for configural (a) and featural data (b)

3.1 Configural Processing

When the face recognition task relies purely on configural information, the main result is a strong and statistically significant positive correlation between HP and RH lateralization ($r = 0.73$, $p < 0.001$). In this case, HP and RH go together. HP and RH lateralization increase from baseline datasets to datasets with bigger spacing, i.e., with increasing stimulus dissimilarity ($t(9) = 7.32$, $p < 0.001$; $t(9) = 7.1$, $p < 0.001$).

3.2 Featural Processing

When face recognition task relies purely on featural information, the main result is a statistically significant negative correlation between HP and RH lateralization ($r = -0.496$, $p < 0.05$). In this case, HP and RH do not go together. HP increases whereas RH lateralization decreases from baseline datasets to datasets with bigger featural changes, i.e., with increasing stimulus dissimilarity ($t(9) = 2.93$, $p < 0.05$; $t(9) = -4.04$, $p < 0.05$).

4 Discussion and Conclusion

Here we investigated the relationship between HP and RH lateralization in configural and featural face recognition tasks through computational modeling. Our model implements a theory of hemispheric asymmetry in perception, the DFF theory, which posits a LSF bias in the RH and a HSF bias in the LH; this model and some variants have been shown to be able to account for both RH lateralization and HP in face recognition [14,19,20]. This study is the first computational work to show that for face stimuli, RH lateralization and holistic processing can be positively or negatively correlated depending upon the nature of the task: respectively configural or featural. A previous work [21] using letters arranged in a deformable triangular configuration as stimuli found also a negative correlation between HP and RH lateralization in a featural task and a weak positive correlation for a configural task.

Our finding of a positive correlation between HP and RH lateralization for the configural face recognition task is reminiscent of the fMRI findings [6,7] linking the HP effect to brain activation in face selective areas especially in the RH. Thus, our results suggest that face processing in real life may rely more on configural than featural information; this is consistent with the finding that configural/second-order spatial relation information is more important in face recognition than in the recognition of other visual object classes [12]. Besides, the finding of reduced HP and increased RH lateralization in expert Chinese character recognition [10] matches well with our finding of a negative correlation between HP and RH lateralization when the recognition task relies mainly on featural information, since expert Chinese character processing essentially involves featural processing and is invariant to configural changes [10].

To conclude, the present work using realistic face stimuli constituted new evidence to call in question the validity of the common assumption of holistic processing being a property of right hemisphere. Our results suggest that HP and RH lateralization are separate processes that can be influenced differentially by task requirements.

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