



The neural signature of spatial frequency-based information integration in scene perception

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Abstract

Visual perception is a process of information integration. In this study, we examined the neural signature of spatial frequency-based information integration in scene perception. We used a two-stage model to investigate the neural mechanism of scene perception. In the first stage, the visual system processed the low-spatial-frequency (LSF) information and extracted the global structural information. In the second stage, the visual system processed the high-spatial-frequency (HSF) information and extracted the local structural information.

We used functional magnetic resonance imaging (fMRI) to examine the neural activity in the visual system during scene perception. The results showed that the visual system processed LSF and HSF information in parallel. The visual system extracted the global structural information from LSF information and extracted the local structural information from HSF information. The visual system integrated the global and local structural information to perceive the scene.

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Keywords Scene perception · fMRI · Spatial frequency · Information integration

Introduction

Visual perception is a process of information integration. In this study, we examined the neural signature of spatial frequency-based information integration in scene perception.

We used a two-stage model to investigate the neural mechanism of scene perception.

In the first stage, the visual system processed the low-spatial-frequency (LSF) information and extracted the global structural information.

In the second stage, the visual system processed the high-spatial-frequency (HSF) information and extracted the local structural information.

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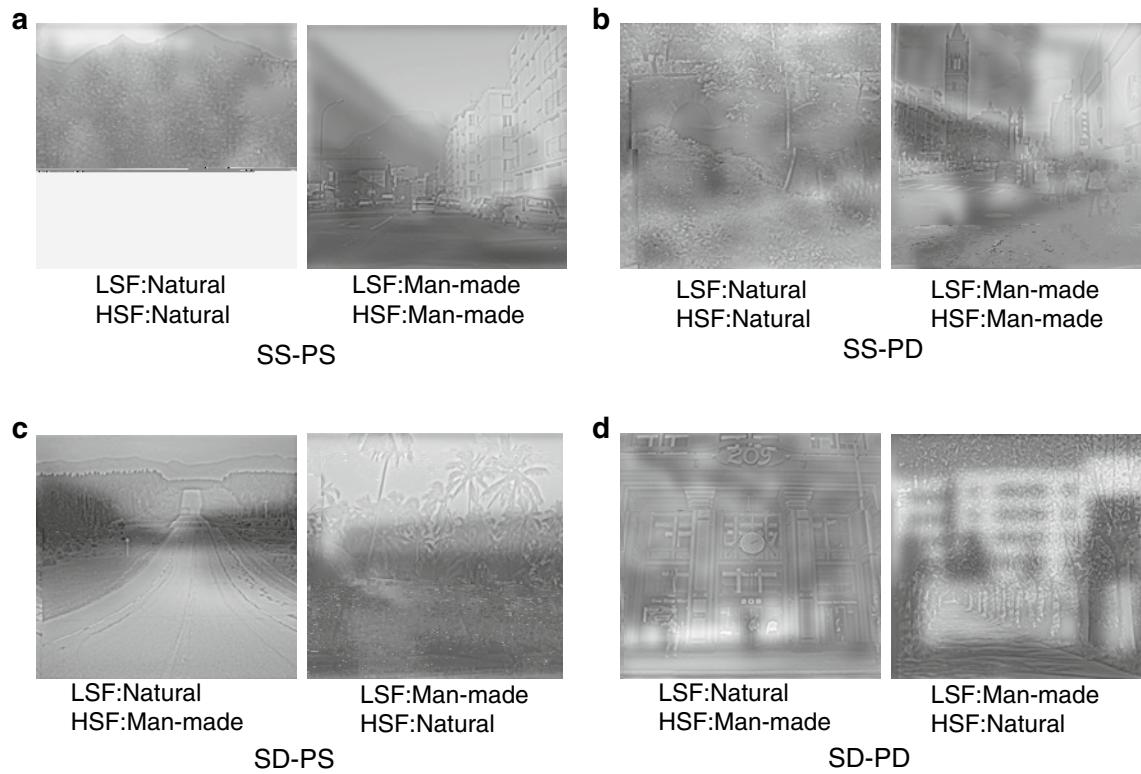
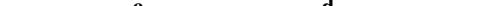
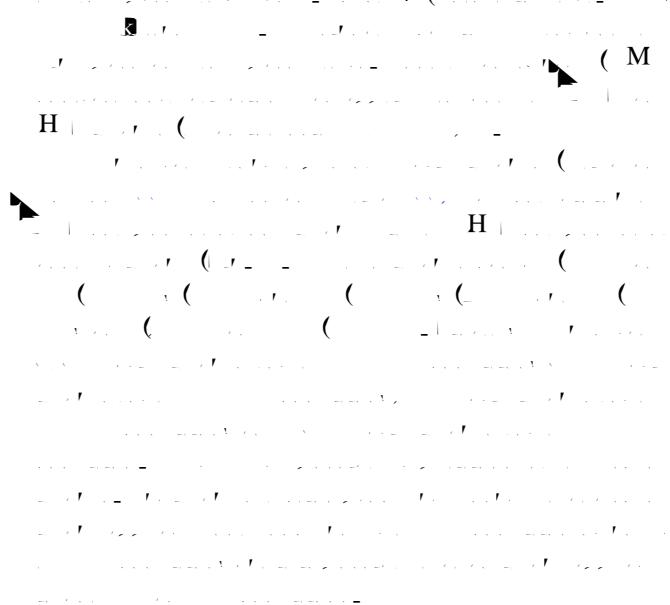


Fig. 1 E 

_____ \leq _____ %

SS PD, *SD PS*, *SD PD*

It is also possible to use the *lens* command to change the *lens* of a *Table*. This is done by specifying the new *lens* as the argument to the *lens* command. For example, if we want to change the *lens* of the *Table* *t* to *lens* *l2*, we can do so by running the command *lens l2 t*.



Design

For each of the four design conditions, the participants were asked to perform a task involving a sequence of 10 items. Each item was a square containing a letter and a number (e.g., A1, B2, C3, D4, E5, F6, G7, H8, I9). The letters were positioned at the top-left corner of the square, and the numbers were positioned at the bottom-right corner. The letters and numbers were in black font. The squares were arranged in a 5 × 2 grid, with the first five items in the first column and the last five items in the second column. The participants were instructed to read the letter and number of each item and then to respond by pressing a key on a keyboard. The letters A through I corresponded to the keys F1 through F9, respectively. The numbers 1 through 9 corresponded to the keys F10 through F18, respectively. The participants were also instructed to ignore the letter and number of the first item (A1) and to respond only to the letter and number of the remaining nine items (B2 through I9). The participants were given a 10-s break after each item. The task ended after the 10th item.

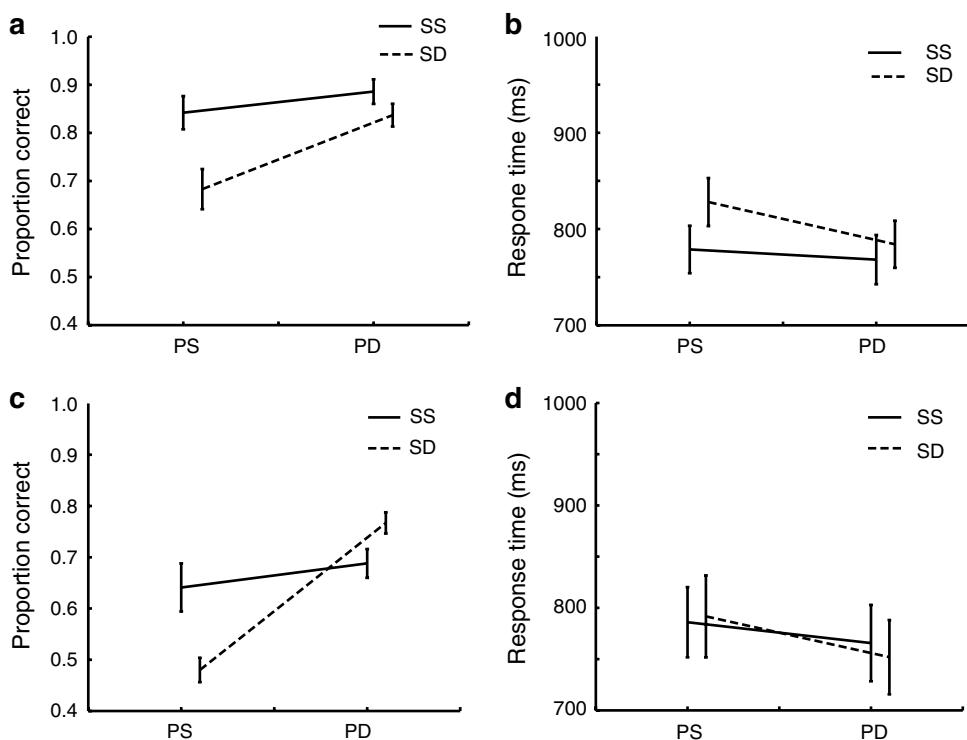
Results

The results showed that the participants' accuracy was significantly higher for the first item (A1) than for the remaining nine items (B2 through I9).

The results also showed that the participants' accuracy was significantly higher for the second item (B2) than for the remaining eight items (C3 through I9). The results further showed that the participants' accuracy was significantly higher for the third item (C3) than for the remaining seven items (D4 through I9). The results also showed that the participants' accuracy was significantly higher for the fourth item (D4) than for the remaining six items (E5 through I9). The results further showed that the participants' accuracy was significantly higher for the fifth item (E5) than for the remaining five items (F6 through I9). The results also showed that the participants' accuracy was significantly higher for the sixth item (F6) than for the remaining four items (G7 through I9). The results further showed that the participants' accuracy was significantly higher for the seventh item (G7) than for the remaining three items (H8 through I9). The results also showed that the participants' accuracy was significantly higher for the eighth item (H8) than for the remaining two items (I9).

Fig. 2

a Proportion correct for the SS and SD conditions. **b** Response time (ms) for the SS and SD conditions. **c** Proportion correct for the SS and SD conditions. **d** Response time (ms) for the SS and SD conditions. Error bars represent standard error of the mean.

**Table 1**

Performance measures for the SS and SD conditions

Long exposure		Short exposure		Long exposure		Short exposure	
(± SEM)	(%)	(± SEM)	(%)	(± SEM)	(%)	(± SEM)	(%)
SS	SD	SS	SD	SS	SD	SS	SD

the SS condition. This was supported by a significant interaction between condition and exposure time ($F(1, 18) = 11.5, p < 0.01$). In contrast, the proportion correct for the SD condition increased significantly over exposure time ($F(1, 18) = 10.1, p < 0.01$) and was significantly higher than the SS condition ($F(1, 18) = 12.1, p < 0.01$). The response times for the SS condition were significantly faster than those for the SD condition ($F(1, 18) = 10.4, p < 0.01$) and decreased significantly over exposure time ($F(1, 18) = 10.1, p < 0.01$). The response times for the SD condition were significantly slower than those for the SS condition ($F(1, 18) = 10.4, p < 0.01$) and did not change significantly over exposure time ($F(1, 18) = 0.2, p = 0.6$).

The results of the second experiment indicated that the SS condition was more effective than the SD condition in reducing the effect of stimulus familiarity on performance. This was supported by a significant interaction between condition and exposure time ($F(1, 18) = 11.5, p < 0.01$). In contrast, the proportion correct for the SD condition increased significantly over exposure time ($F(1, 18) = 10.1, p < 0.01$) and was significantly higher than the SS condition ($F(1, 18) = 12.1, p < 0.01$). The response times for the SS condition were significantly faster than those for the SD condition ($F(1, 18) = 10.4, p < 0.01$) and decreased significantly over exposure time ($F(1, 18) = 10.1, p < 0.01$). The response times for the SD condition were significantly slower than those for the SS condition ($F(1, 18) = 10.4, p < 0.01$) and did not change significantly over exposure time ($F(1, 18) = 0.2, p = 0.6$).

Experiment 2

Method

Observers

Eleven observers (mean age ± SD = 24.6 ± 4.4 years) participated in this experiment. All participants had normal or corrected-to-normal vision and were naive to the purpose of the study.

EEG was recorded from 12 channels (Fz, Cz, Pz, O1, O2, F3, F4, C3, C4, P3, P4, O1, O2) using a NeuroScan system (NeuroScan, Compumedics, Charlotte, NC, USA). The sampling rate was 500 Hz and the bandpass filter was 0.5–40 Hz.

Stimuli

EEG stimuli were presented in a 2 × 2 factorial design. The first factor was the stimulus type (H or U) and the second factor was the presentation condition (EE or H). The four stimulus conditions were: H_EE, H_H, U_EE, and U_H. Each stimulus was presented once in a random order. The duration of each stimulus was 1 s. The interstimulus interval was 1 s. The presentation order of the four stimulus conditions was counterbalanced across subjects.

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EEG recording and analysis

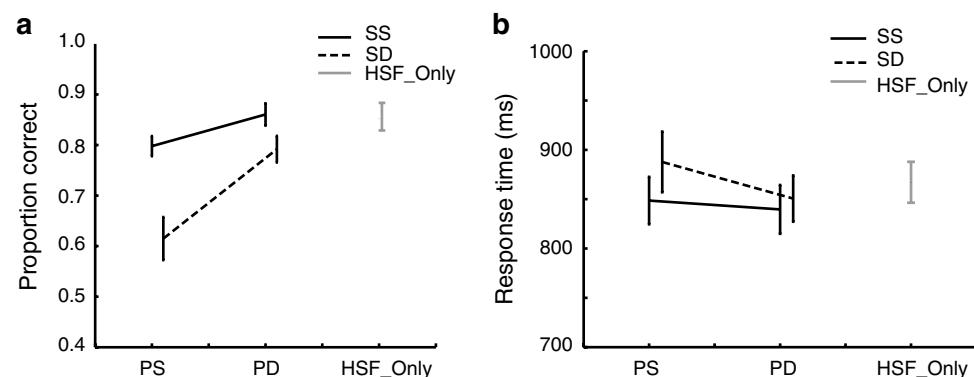
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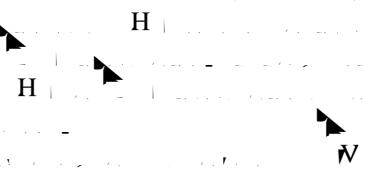
Table 2

Mean proportion correct and response times

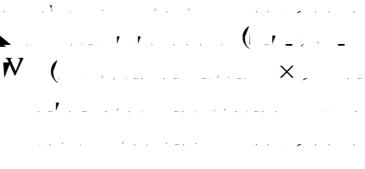
	(± EM)	(± %)	(± %)	(± %)	(± %)	(± %)
H_EE	0.82	0.02	0.02	0.02	0.02	0.02
H_H	0.87	0.02	0.02	0.02	0.02	0.02
U_EE	0.64	0.02	0.02	0.02	0.02	0.02
U_H	0.79	0.02	0.02	0.02	0.02	0.02

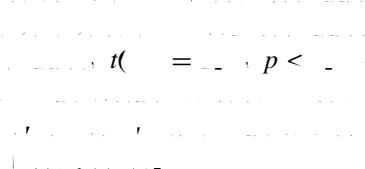
Fig. 3 Mean proportion correct and response times. **a** Proportion correct. **b** Response time (ms). Error bars represent standard error of the mean (SEM). SS standard stimulus, SD stimulus deviant, HSF_Only high stimulus frequency



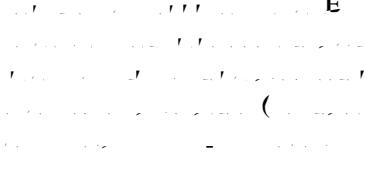
and $t(\cdot) = \cdot \wedge p < \cdot$ and $F(\cdot) = \cdot \wedge p < \cdot$ and $F(\cdot) = \cdot \wedge p = \cdot$.


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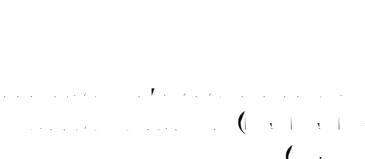
For \mathbf{EE} , we have $t(\cdot) = \cdot \wedge p < \cdot$ and $F(\cdot) = \cdot \wedge p < \cdot$ and $F(\cdot) = \cdot \wedge p = \cdot$.


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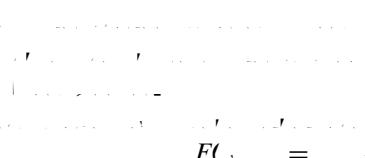
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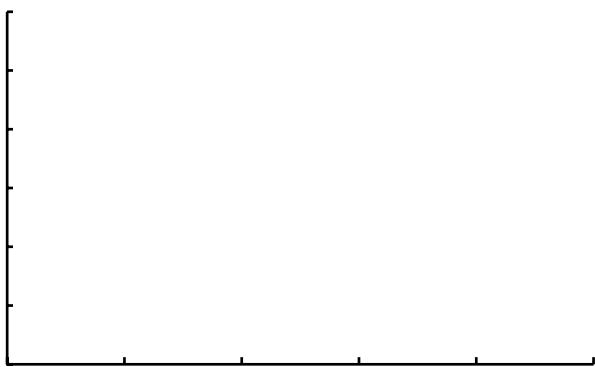

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Discussion

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and the **K** key. The **E** key was used to indicate the end of the task. The **H** key was used to indicate the start of the task. The **M** key was used to indicate the start of the task. The **EE** key was used to indicate the end of the task.

The task was divided into two phases. In the first phase, the participant had to type the letter **K** 10 times. In the second phase, the participant had to type the letter **E** 10 times. The task was divided into two phases. In the first phase, the participant had to type the letter **K** 10 times. In the second phase, the participant had to type the letter **E** 10 times.

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H + **K** + **M** + **E**

H |

Acknowledgments

E **M**

$\mathbf{K}_\text{M} = \mathbf{M}(\mathbf{I} - \mathbf{A})^{-1}$

References

- M ()
M K ()
M H ()
H E ()
U ()
K ()
M M E ()
M W ()
M H ()
E ()
M M ()
M ()
W ()
W ()

$$\begin{aligned} \mathbf{E}_{\text{ext}}(t) &= (\mathbf{E}_{\text{ext}}(t_0) - \mathbf{E}_{\text{ext}}(t)) \mathbf{H}(t) + \mathbf{E}_{\text{ext}}(t) \\ \mathbf{W}_{\text{ext}}(t) &= (\mathbf{W}_{\text{ext}}(t_0) - \mathbf{W}_{\text{ext}}(t)) \mathbf{H}(t) + \mathbf{W}_{\text{ext}}(t) \\ &= (\mathbf{E}_{\text{ext}}(t_0) - \mathbf{E}_{\text{ext}}(t)) \mathbf{H}(t) + \mathbf{E}_{\text{ext}}(t) \end{aligned}$$