Encoding of global and fine information about visual stimuli in the primate temporal cortex

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When we see a person's face, we would notice different kinds of information in it, for example, the person's feelings, age, or information related to his/her identity. How does the brain process such a complicating visual stimulus? We found that neurons in the monkey inferior temporal cortex represented multiple aspects of face-stimuli in their temporal firing pattern. Either as individual single neurons or as a population of neurons, neuronal responses represented visual information at different categorical levels at different time periods, namely global categorization would be processed earlier than finer characteristics of the stimulus. This coding pattern could be related to associative memory about visual stimuli in the temporal cortex.

Keywords: monkey, inferior temporal cortex, face, information, associative memory

Introduction

Inferior temporal (IT) cortex is known to play an important role in normal visual pattern recognition (Iwai and Mishkin, 1976). It has been reported that some neurons in the superior temporal sulcus (STS) and the IT cortex of macaque monkeys respond to faces (Gross 1973). Responses of neuronal population in IT cortex are known to encode individual faces based on their physical features (Young and Yamane, 1992; Hasselmo, 1989) while responses of neuronal population in the STS are known to represent facial expressions (Hasselmo, 1989). Since face images contain different kinds of information simultaneously, we investigated how neurons in the monkey temporal cortex process such complex information over time (Sugase et al., 1999).

Information coded by single units

In total, 1,874 single units were recorded in the inferior temporal (IT) cortex of two monkeys using a simple fixation task (Sugase et al., 1999). We tested each unit while the monkey was looking at a visual stimulus among 38 test stimuli. The test stimuli consisted of 16 monkey faces (4 models with 4 expressions), 12 human faces (3 models with 4 expressions), and 10 geometric shapes (rectangles and circles, each in one of five colors, red, blue, green, pink, and brown). In the task, each stimulus was presented for a period of 350ms. About 10% of the neurons in the temporal cortex were responsive either to monkey or human faces (Fig.1a). We analyzed what kind of information was coded in responses of individual single unit using information theoretic measure, and found that single neurons encoded two different scales of information in their firing patterns starting at different latencies (Fig.1b). Information about global categorization, namely monkey faces vs. human faces vs. shapes, was conveyed in the earliest part of the responses. Finer information within the each member of the global categorization, namely information about identity or expression, was represented later, beginning on average 51 ms after global information (Sugase et al., 1999).

Information coded by population of neurons

By the analysis of individual neurons, we found that information about the global categorization increased earlier than the information about the finer categorization. We then studied temporal aspects of information coding by the population of neurons (Matsumoto et al, 2001). Using multi-dimensional scaling (MDS), we confirmed that the global categorization occurred approximately 50 ms earlier than the finer categorization. We applied a clustering analysis, mixture of Gaussians analysis, to see whether or not both the global and fine categorizations were close approximations about what the neuronal responses represented. In the early part of the responses, clusters corresponding to the global categorization, monkey faces vs. human faces vs. shapes, were observed. In the later part of the responses, each cluster in the early part became separated into sub-clusters corresponding to either monkey expression, human identity, or shape form. We also found that the global categorization was maintained even after the appearance of sub-clusters. Thus, along time, a hierarchical relationship of the test stimuli was represented. These results indicate that the representation of facial information may be completed in IT cortex (Matsumoto et al, 2001).

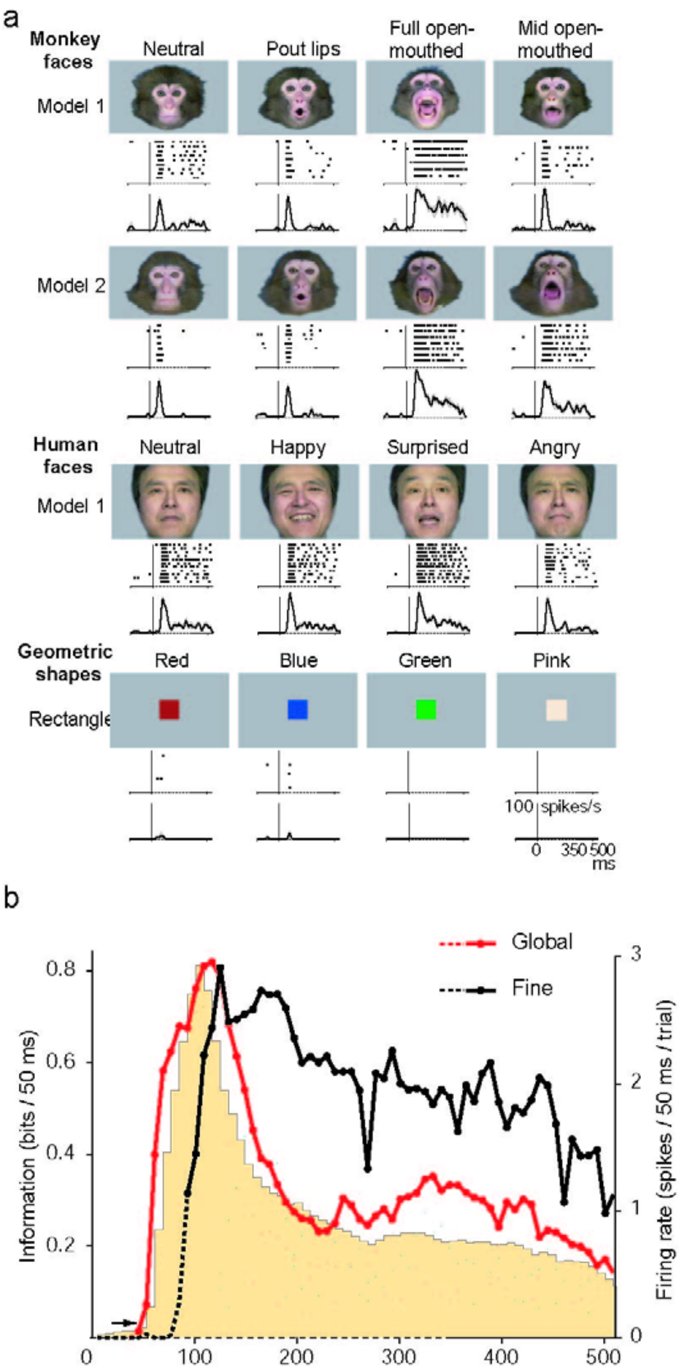

Figure 1. a. Response of a face-responsive neuron. Each diagram consists of a stimulus image, a raster plot of the response, and a spike density plot, in the first, second, and third rows, respectively. Responses only to 16 test stimuli are shown. This neuron responded to both monkey faces and human faces at least transiently, and didn't show a response to geometric shapes. The neuron changed its temporal firing pattern depending on monkey expressions. A sustained response was observed to full open-mouthed faces, while a transient response was observed with other facial expressions. b. Information transmission rate of the face-responsive neuron. A red trace indicates information transmission rate of a global category, i.e. monkey faces vs. human faces vs. geometric shapes. A black trace indicates information transmission rate of a fine category, in this case monkey expression. The earliest information was the global, and followed by the fine information. Solid and broken traces indicate significant and non-significant information, respectively. In the time axis (abscissa), the time of stimulus onset is 0 ms and the duration of stimulus presentation is indicated as a dashed line. Information transmission rate was calculated using numbers of spike discharges within 50-ms sliding windows that was moved in 8-ms intervals. A yellow histogram shows an averaged firing rate in each time window. An arrow indicates the threshold criterion for the response latency (modified from Sugase et al., 1999).

Relation to associative memory

The dynamics of information representation in the IT neurons might permit intra-areal contribution and/or feedback from other areas. We investigated whether an intra-areal neuronal mechanism could ensure the dynamics of the neurons by employing an attractor network, specifically an associative memory model (Matsumoto et al., in preparation). We found that the dynamics of the associative memory model was qualitatively equivalent to the behavior of IT neuronal responses. Thus, IT cortex may have a neuronal mechanism which corresponds to the associative memory model.

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