The Development of Mirror Neurons Representing Facial Expression: A Computer Modelling Study

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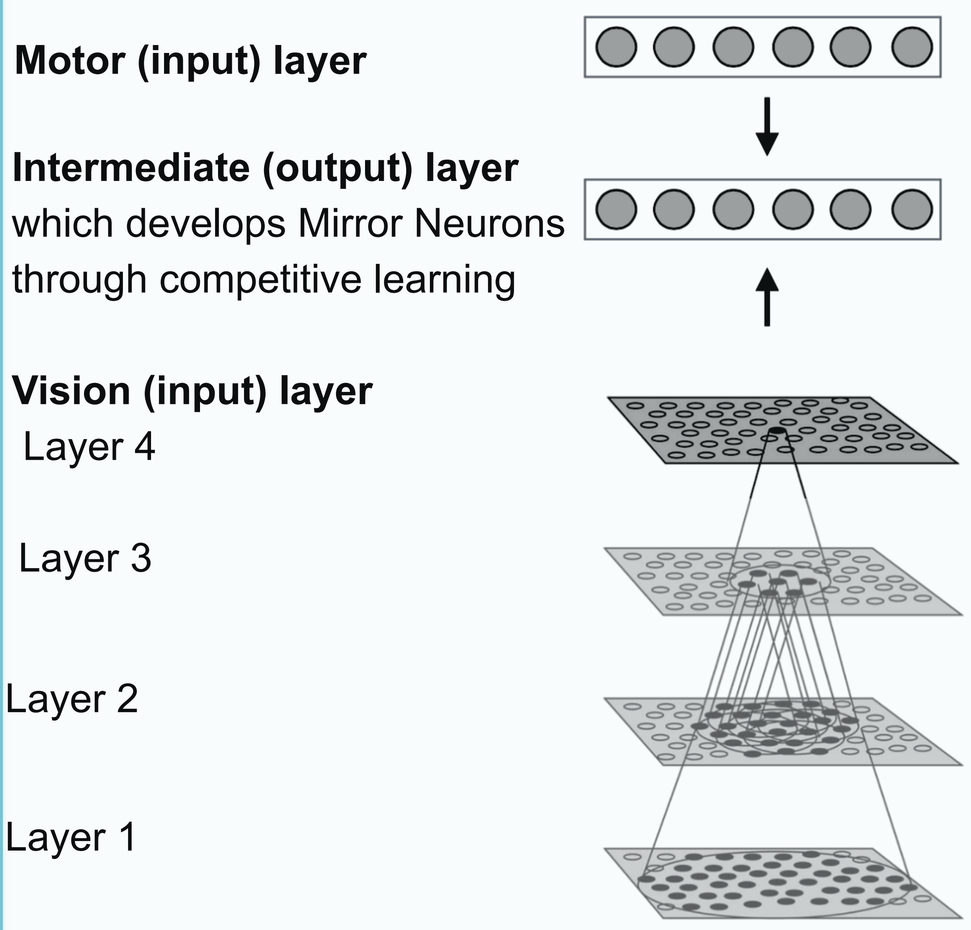
Abstract

Previous research has shown that humans automatically and spontaneously show facial response patterns that are congruent to viewed emotional facial expressions. Moreover, similar neural substrates seem to be recruited and co-active in the production as well as the observation of emotional facial expressions. It has been suggested that the computational mechanisms that may underlie these vicarious emotional activations could be based on the development of mirror-like neurons that emerge through associative learning mechanisms. In this work we model the development of mirror neurons that encode facial expressions in the infant brain during interaction with either of its parents. We show how temporally correlated imitation of facial expressions in early social interactions could drive the development of mirror neurons in the infant using Hebbian learning. More importantly, we explore the development of such neuronal responses across varying degrees of correlation and temporal lags between the seen and produced facial expressions.

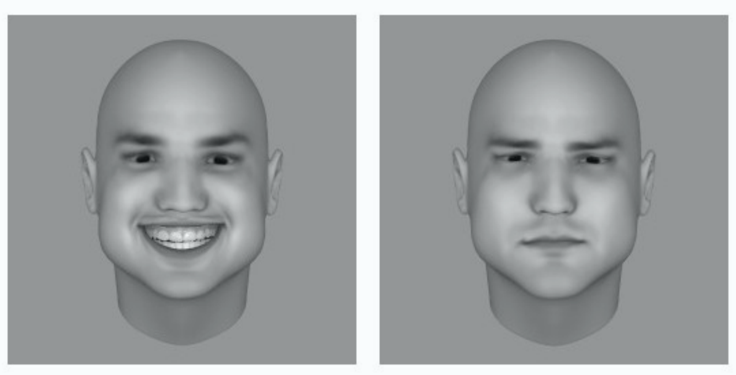
Model

We present a self-organised neural network model that incorporates a visual module composed of a hierarchical model of successive neuronal layers and a motor module that represents the current facial expression of the infant. The outputs of the vision system and the facial motor system then converge onto an intermediate neuronal layer, in which mirror neurons may develop. Using this model, we explore the learning mechanisms that may underpin the development of mirror neurons encoding facial expression in the infant brain during social interaction with its parent. The simulations show that after training, the output neurons in our network learn to respond selectively to a preferred facial expression (e.g. Happy or Sad) regardless of whether the infant generates the expression or the infant sees the parent displaying that expression.



This vision module is based on an established, biologically detailed, hierarchical neural network model of the primate ventral visual pathway, called VisNet. The hierarchical series of 4 neuronal layers of VisNet have been related to the following successive stages of processing in the ventral visual pathway: V2, V4, the posterior inferior temporal cortex, and the anterior inferior temporal cortex.

In particular, the vision model architecture is based on the following: (i) a series of hierarchical competitive networks with local graded lateral inhibition, (ii) convergent connections to each neuron from a topologically corresponding region of the preceding layer, (iii) synaptic plasticity based on a local associative learning rule such as the Hebb rule.

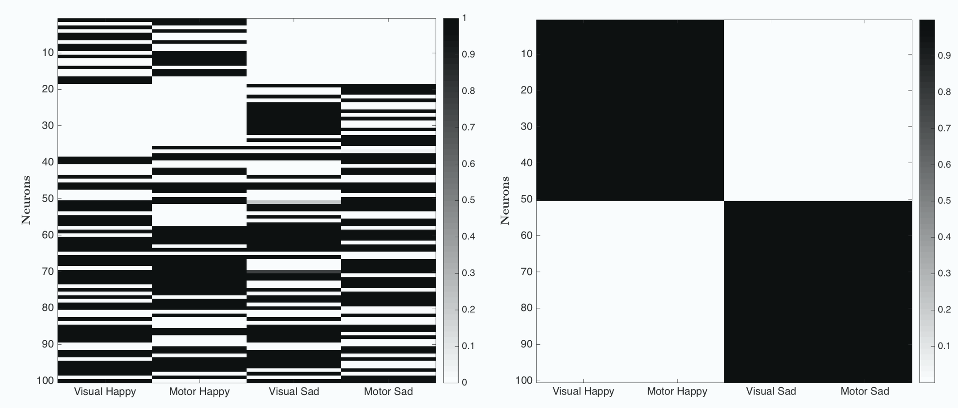


The VisNet model was pre-trained on randomised face images in order to develop subpopulations of neurons that represented either happy or sad facial expressions whenever an image of the parent's face was presented. After this pre-step, during each training update, the infant's current facial expression is represented by a binarised (i.e. 0/1) pattern of firing activity by the motor module. At the same time, the parent's face is presented to the vision module.Then activity from the motor module and the 4th layer of the vision module is propagated through feedforward connections to the intermediate (output) layer, with the connections being modied by a simple Hebbian learning rule.

The figure above represents the happy (left) and sad (right) images of the parent's face presented to the vision module during training and testing the development of mirror neurons.

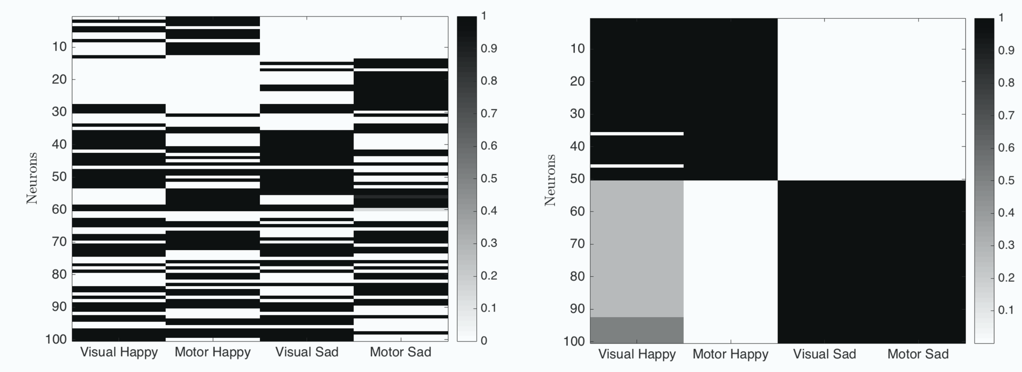
Results

In the first simulation study, we demonstrate how the intermediate (output) layer may develop mirror neurons when trained on a sequence of visual and motor inputs representing an interaction between the infant and its parent. We always use simulated data, in which the infant and parent switch their facial expressions through time between the two expressions happy and sad. In this first demonstration, it is assumed that the parent always mimics the infant's expression accurately on each timestep.



The figure above shows the firing rates of the neurons in the intermediate (output) layer. Results are shown before training (left) and after training (right), where the neurons have been been reordered according to which input patterns they respond to. After training all of the neurons in the intermediate layer either respond selectively to both visual happy and motor happy inputs or respond to both visual sad and motor sad inputs. The figure below shows the firing rates of the neurons in the intermediate (output layer) for the third simulation.

In the second simulation study, we investigated how well the model performed in the more ecologically realistic situation where the parent failed to mimic the facial expression of the infant with perfect accuracy. We gradually increased the percentage of the training timesteps for which the parent had the opposite expression to the infant. In the third simulation we created an artificial sequence of training data in which the parent tracks the changing facial expression of the infant with a temporal lag. Each change in the infant's facial expression is thus followed by a change in the parent's facial expression.



Discussion

In this paper we have presented a overarching neural network model comprised of three separate modules: the vision (input) module, the motor (input) module, and the intermediate (output) layer that develops mirror neurons through competitive learning.The vision module represents successive neuronal layers of the temporal visual cortex, which has been found to contain neurons that represent particular facial expressions.The motor module represents the ventral premotor cortex and encodes motor efference signals representing the current facial expression of the infant. The intermediate output layer receives afferent synaptic connections from the vision module and the motor module. The results provide a detailed demonstration of how a biologically plausible neural network architecture where the synaptic weights are updated using a Hebbian learning mechanisms can account for the emergence of mirror-like neurons that can become vicariously activated in response to a viewed emotional facial expression. Moreover, we showed how these response properties could still emerge under more ecologically realistic training conditions.

References

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