Explaining Neonate Facial Imitation from the Sensory Alignment in the Superior Colliculus

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***Abstract*—We propose a developmental scenario for explaining neonatal imitation. We hypothesize that the early maturation of the superior colliculus (SC) at the fetal period may strongly contribute to the construction of the social brain. We underly two mechanisms in SC potentially important which are (1) spatial topological organization of the unisensory modalities and (2) the conformed sensory alignment between these different modalities. We make a neural model of SC learning from a fetus facial tissues and from the fetus eyes and we show preference for face-like patterns.**

***Index Terms*—neonatal imitation, multimodal integration, superior colliculus, facial preference.**

I. Introduction

Neonatal imitation is perhaps the phenomenon that crystallizes the most the nature versus nurture debate. It questions us whether or not newborns possess inborn social skills, which is a radical leap out against pagietian development which considers social cognition as the lastest stage of cognitive development. Nonetheless, several evidences taken from prenatal observations permit to infer an intermediate scenario in which sensorimotor learning at the fetal stage may give the background for a minimal social brain [1]. For instance, fetal behavioral and anatomical observations show evidences for the control of eye movements and of facial behaviors during the third trimester of pregnancy whereas specific sub-cortical areas, like the superior colliculus (SC) and the striatum appear to be functionally mature to support these behaviors [2]. These observations suggest that the newborn is potentially mature for developing minimal social skills. In this abstract, we propose that the mechanism of sensory alignment observed in SC is particularly important for enabling the social skills observed at birth such as facial preference and facial mimicry [3], [4].

The superior colliculus has a particular neural architecture that may ease multimodal integration for simple social skills. For instance, each modality is constructed into superimposed topographical layers that converge unidirectionally to an intermediate multimodal layer; that is there is no recurrent connections within and between the maps [5]. First, the visual map is constructed into a retinotopic layer whereas the somatotopic map is constructed into a head-centered reference frame. Second, synaptic nerves/connections from each layer dive into the intermediate layer almost in parallel, which permits the simple sensory alignment without topological distortion. We hypothesize that sensory alignment with hebbian learning helps multimodal integration and that the intermediate layer exploits this mechanism to connect the somatopic and topographical features of one's own face to the visual and also topographical features of someone else face (i.e., eyes and mouth) [3]. This idea is in line with Meltzoff's Like-Me theory [6] and to Johnson's CONSPEC/CONLEARN midbrain basis for the development of the social brain [1] and Boucena's models of social referencing [4].

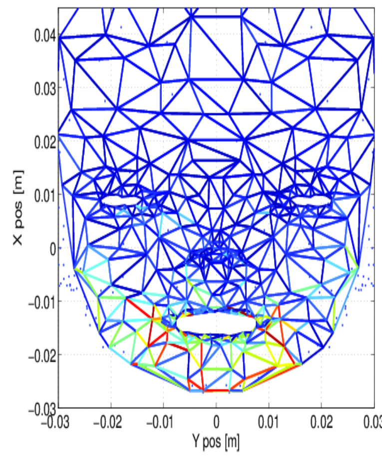

Fig. 1. Face mesh of the fetus model. The distorsion of the facial tissue is simulated as a mass-spring network of 354 tactile points and 1039 springs. Stress and displacement of the facial tissue are rendered by the actions of group muscles around the mouth and the eyes.

II. Methods/Material

We make a computational simulation of the maturing superior colliculus connected to a simulated facial tissue that replicates some attributes of the bio-mechanical properties of the fetus' face, see Fig. 1. We model how the incoming tactile information is used to direct visual attention toward faces. We suggest that the unisensory superficial visual layer (eye-centered) in SC and the deep somatopic layer (face-centered) in SC are combined into an intermediate layer for visuo-tactile integration and that multimodal alignment in this third layer allows newborns to detect faces and to mimic them. We model the neural populations with integrate-and-fire neurons that capture the spatio-temporal dynamics from the two sensory modalities. The detection of structured patterns is an important attribute for preserving the topology of each modality in each

A. Pitti, P. Gaussier, M. Quoy are in the Laboratory ETIS, UMR CNRS 8051, the University of Cergy-Pontoise, ENSEA, France.

Y. Kuniyoshi is in the ISI Laboratory, Dept. of Mechano-Infomatics, Grad. School of Info. Science and Technology, University of Tokyo.
E-mail: alexandre.pitti@u-cergy.fr

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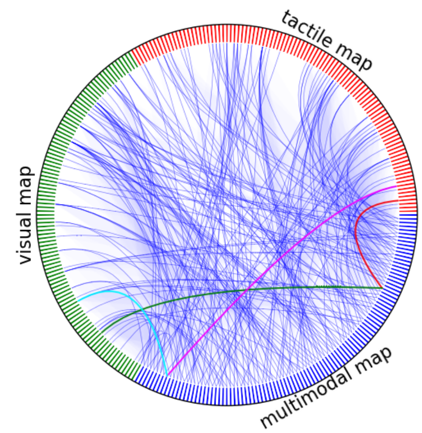

Fig. 2. Connectivity circle linking the visual and tactile maps (resp. green and red) to the bimodal map (blue). The colored links correspond to localized visuo-tactile stimuli on the nose (green/red links) and the right eye (cyan/magenta links).

map. The neural populations work as a Kohonen-like algorithm except that we model the maturing period of SC. Learning is based on the reinforcement of the neurons synaptic links following hebbian association rules. We add also an activity-dependent mechanism based on novelty detection in order to construct the topology of the neural map by preserving at the same time the existing neurons' topology and by adding new neurons that refine it.

III. Results

After we complete the learning stage within each map through hebbian reinforcement learning, we show that each topology respects the retinopic topography of the eye and the somatotopic topography of the face, as seen in the SC. Then, the two unisensory layers convey the unimodal information through their synapses to the common intermediate layer. The multimodal layer reinforces the contingent synaptic links that align the visuo-tactile sensory information from each other. The resulting map creates a mixed spatial representation based on the eye- and the face-centered reference frame; see Fig. 2.

As a result, when rotating a three-dots face-like pattern in front of the eye-field, we observe sensitivity of the network for certain orientations only. That is, when the three dots align well with the caricatural eyes and mouth configurational topology (i.e.facial identification); see Fig.3.

Second, the neural activity taken from the intermediate visuo-tactile map during observation of certain facial expression like surprise and stance triggers the neurons to the characteristic visual configurational patterns of the face during rapid changes. This situation occurs because of sensory alignment and of the high correlation with the tactile distribution of its own face. We can imagine then that if the intermediate cells feed-forward this activity to the corresponding facial motor activity, then imitation will occur.

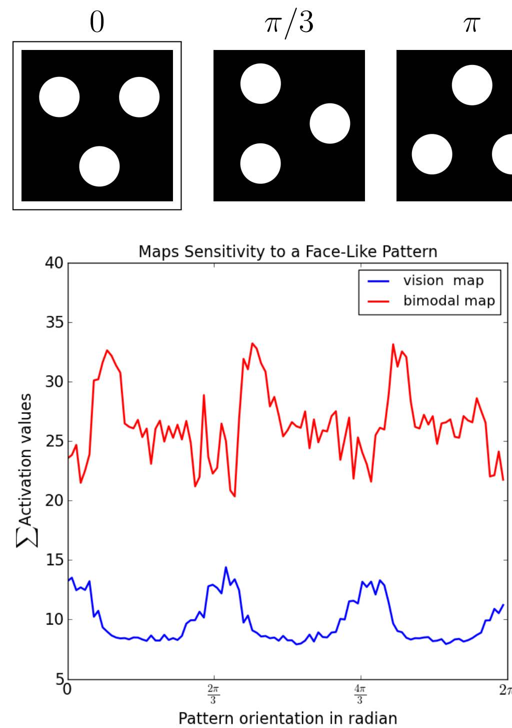

Fig. 3. Sensitivity to face-like patterns for certain orientations. When rotating the three dots pattern centered on the eye, the neural activity within the visual map and the bimodal map gets higher only to certain orientations.

IV. Discussion

We have introduced a developmental model of the SC starting from the fetal stage in the context of primitive social behaviors. In comparison to normal stimuli, we propose that faces are particular information as the visual and somatic maps in the SC are perfectly aligned topologically. We suggest that the multimodal alignment may influence neonates to produce simple social skills, like recognizing faces' configurational patterns (eyes and mouth disposition) and to generate simple mimicry. SC may shape then the organization of cortical structures for more complex behaviors like joint attention, recognition of facial expressions, intention to others.

Acknowledgments

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