Is the developmental order of fetal behaviors self-organized in an uterine environment?

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***Abstract*—Developmental order is one of the fundamental issues of developmental science. de Vries et al. 1982 observed fetal behaviors and suggested that the orders of the timing of first appearance of the behaviors are consistent among fetuses in utero. We have investigated the fetal behavioral development by a computer simulation that has a whole fetal musculoskeletal body, a uterine environment and a nervous system. In this paper, we analyzed data of our simulated fetal behaviors from a perspective of the first appearance. The analysis shows that the order is consistently same as the observation by de Vries et al. 1982 regardless of the value of a nervous system model parameter. The result indicates that physical constraints, including musculoskeletal system, tactile cell distribution, and uterine environment, induce the self-organization of the developmental order.**

I. Introduction

Developmental order from fetal to child periods is a fundamental issue of developmental science because of strong interests regarding medical treatments, educations and so on. Especially, it is conceivable that understanding of fetal development is useful for treatments of preterm infants, including nesting and swaddling, while recent studies revealed that preterm infants, who have less experiences of uterine environments, have more risks of Autistic Spectrum Disorder (ASD) [1]. If we would understand a mechanism of developmental order of fetus, treatments of preterm infants can be improved by knowledge of what kind of stimulus facilitate infants' development and when the stimulus should be supplied to preterm infants.

For the purpose of the understanding of fetal development, we have investigated the fetal behavioral development by a computer simulation [2], [3]. The simulator has the following features.

- A physical fetal body (Figure 1): A whole body musculoskeletal system with198 muscles and 1542 merkel's tactile disks. Body parameters are set equivalent to 20 gestational weeks.
- An uterine environment: It consists of amniotic fluid and uterine wall.
- A nervous system (Figure 2): It consists of medula oblongata and spinal cord. Hebbian rule make connections between the tactile cells and the motor neurons.

de Vries et al 1982 [4] observed development of fetal behaviors by ultrasound imaging, categorized the behaviors to 16 classes, and recorded the starting time of the behaviors. The behaviors are as follows.

1) **General Movements (GMs)**: It is spontaneous smooth and random movements observed from 8-10 gestational weeks, and not reflective against external stimuli.
2) **Isolated Arm/Leg Movements**: Characteristics of the movements are jerkiness and independent from any other body parts' movements starting from around 10 gestational week.
3) **Hand/Face Contacts**: The behaviors are defined as the hands touch the face for more than 1 [sec]. They occur isolated or within GMs after about 11 weeks.

The ultrasound recordings implied that the orders of the timing of the first appearances of the behaviors of fetuses are consistent.

Using the simulation, we validated our hypothesis about the fetal behavioral development, in which the behaviors are induced by fetal tactile experiences, including isolated arm movement and hand/face contacts, in a self-organizing manner in a womb. However, the order of the appearances have not been analyzed yet.

In this paper, we analyze data of simulated fetal behaviors from a perspective of the first appearance of the behaviors.

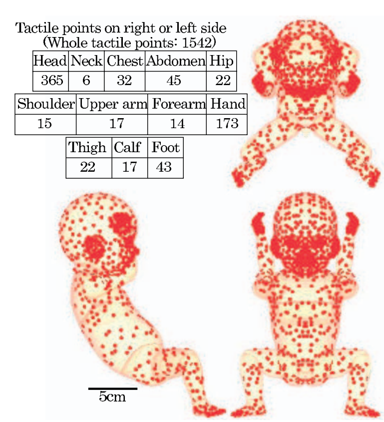

Fig. 1. A simulation model of fetus with tactile cells distributed by two point discrimination.

II. Simulation experiment and analyses

To detect the time of the first appearance of each behavior, we compare the averages of the behavioral indexes by t-test between the initial values and the the values with the learning. The behavioral index for Isolated arm/leg movements is an average of absolute jerk ($\|d^3\boldsymbol{x}/dt^3\|$) for 10 [sec], and the behavioral index for hand/face contacts is contact duration of hand and face for 10 [sec].

The algorithm is as follows.

1) Run a fetal simulation with fixed randomized neural connectivity (without Hebbian learning) as a behavior without uterine experience.
2) Run a fetal simulation with neural connectivity learned by Hebbian learning rule as a behavior with uterine experience. Initial connectivity is random.
3) Calculate the averages and the standard deviations of the index of each behavior for "with-learning" and "without-learning" each 100 [sec] (10 [sec] $\times$ 10 times).
4) Compare behavior indexes between with-learning and without-learning by t-test for 100 [sec].
5) Determine emerging time of behaviors as p-value of t-test is bellow 0.0001 at first.

The time change of the behavioral indexes are shown in Figure 3 and Figure 4. Red areas represent standard deviations for "without-learning" and blue areas represent standard deviations for "with-learning."

To make sure the consistency of the order, we analyzed simulation data from different values of connectivity strength from tactile cells to motor neurons. The results are shown in Figure 5. From the result, the appearance timings become earlier when the gain from the tactile sensation increase. However the orders are consistent regardless of different values of the nervous system model parameter.

III. Conclusion

The analyses showed that the orders that the behaviors emerge are consistent with the observation by de Vries et al 1982. The results suggest that physical constraints, including a musculoskeletal system, tactile cell distribution, and uterine environment, induce the self-organization of the developmental order.

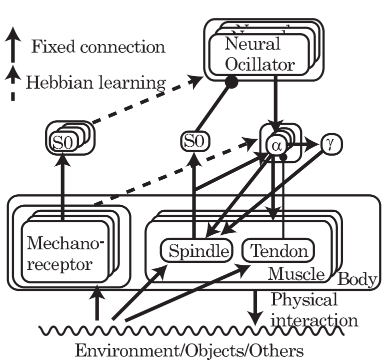

Fig. 2. Our nervous system model with tactile cells.

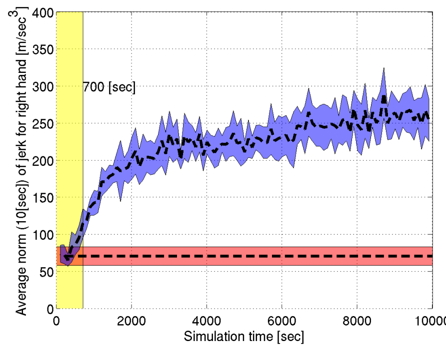

Fig. 3. Average and standard deviation of right hand jerk.

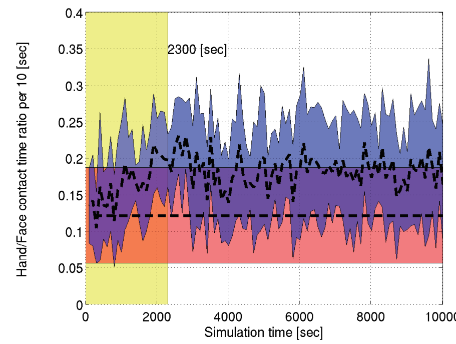

Fig. 4. Average and standard deviation of right hand and face contacts duration ratio per 10[sec].

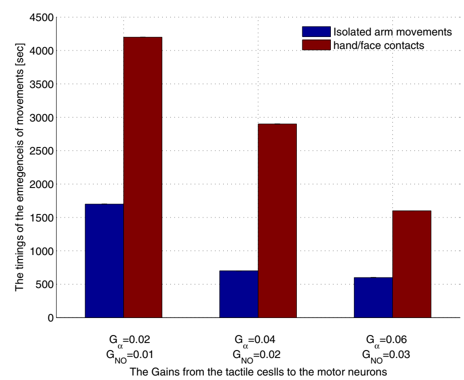

Fig. 5. The moments of onset of ioslated right arm movements and right hand/face contacts

References

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