Multiple Representations for Visuomotor Learning in the Cerebellum: A Functional MRI Study

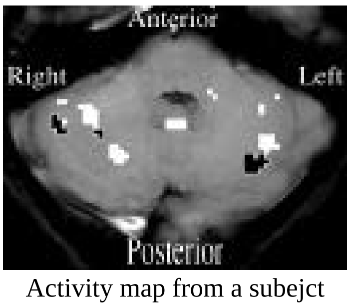
Hiroshi Imamizu[1], Satoru Miyauchi[2], Tomoe Tamada[1], Yuka Sasaki[2], Ryousuke Takino[3], Toshinori Yoshioka[1], Benno Pütz[1] and Mitsuo Kawato[1,4]

[1] *Kawato Dynamic Brain Project, Japan Science and Technology Corporation, Kyoto, Japan;* [2] *Communications Research Laboratory, Tokyo, Japan;* [3] *Shiraume Gakuen College, Tokyo, Japan;* [4] *ATR Human Information Processing Research Laboratories, Kyoto, Japan*

Many neurophysiological and fMRI studies have demonstrated the involvement of the cerebellum in visuomotor learning (1, 2). Our previous study (3) suggested that the cerebellum is not only a detector of sensory-motor error but it also acquires "internal models" for representing visuomotor transformations. Recent computational studies (4, 5) have proposed a hypothesis that there exist multiple representations for visuomotor learning in the central nervous system and that each representation simultaneously learns a different transformation. To examine this hypothesis, we investigated if the different rules for visuomotor transformation evoke activities in different locations in the cerebellum.

Subjects and Methods: Three subjects, aged 22-26 years, manipulated a computer mouse with the right hand so that a corresponding cursor would follow a randomly moving target on the screen (a "tracking task"). The relative distance between the target and the cursor was referred to as the "tracking error" and was used to evaluate the subjects' performance. There were three alternative relationships between the mouse movement and the cursor movement during the task; 1) rotation: $\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} \cos 120^\circ & \sin 120^\circ \\ -\sin 120^\circ & \cos 120^\circ \end{pmatrix} \begin{pmatrix} p \\ q \end{pmatrix}$, 2) integration: $(x, y) = \left(0.04 \sum_{i=1}^{t} p_i, 0.04 \sum_{i=1}^{t} q_i\right)$, and 3) identity map: $(x, y) = (p, q)$. Here, (x, y) denotes the screen coordinates for the cursor position, (p, q) denotes the hand coordinates for the mouse position, and t denotes time. There were two experimental sessions: a rotational session, and an integral session. In each session, the test and baseline periods were alternately repeated eight times. A single period cycle had duration of 35 sec. The relationship was the rotation in the test periods of the rotational sessions while it was the integration in the test periods of the integral sessions. For the baseline periods of the both sessions, it was identity map. The subjects received training for thirteen rotational sessions and thirteen integral sessions. The tracking error decreased as the session number increased. After the training, functional images were scanned in each session using a 1.5 T Siemens scanner equipped with an EPI booster (imaging parameters: 7 mm thick, TR = 4 s, TE = 66 ms, FA = 90˚, FoV = 240 mm by 240 mm, matrix = 128 by 128, axial slices). The target velocity in the baseline periods was changed so that there was no significant difference between the error in the test periods and that in the baseline periods during the scan. This procedure was designed to find activation changes caused by learning the relationships, not by error detection and correction. All images were motion corrected by AIR ver.3.0 and filtered with a two dimensional Gaussian filter (2 pixels at FWHM). We used a cross correlation calculation for each pixel (6) to find regions that produced higher MR signal intensity during the test periods than during each baseline period.

Results and Discussion: The right figure shows a subject's representative activation map. The slice position was at the level of the fourth ventricle. *Black regions* and *white regions* in the cerebellum produced significantly higher (p<0.001) intensity in the test periods of the rotational sessions and in the test periods of the integral sessions, respectively. This result demonstrates that the different rules for visuomotor transformation evoke activities in different locations, hence suggesting the existence of the multiple representations in the cerebellum.



Activity map from a subejct

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