Recognition for Switching of Feedback and Feedforward Process in Motor Internal Model

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ABSTRACT

The internal model was proposed by Kawato [1], in order to express physical motion by associativity of feedback and feedforward control processes. In this paper, we test the internal model in an experiment in which participants push a button on an equipment to match a number displayed on a computer screen. The experimental results can be interpreted as a change in the relative contributions of feedback and feedforward control processes in the internal model.

Keywords

Motion Analysis, Motor internal model, Control Process

1. INTRODUCTION

Among models that analyze motion trajectories in terms of the structure different functional processes, the motion internal model [1] and MOSAIC model [2] are particularly useful. The internal model is based on the model of Allen-Tsukahara and is able to express physical motion by associativity of feedback and feedforward control processes. In this model, movement is controlled well gradually, because the inverse model reduces the error between the desired trajectory and the trajectory realized by a feedforward function.

In this paper, we discuss feedback and feedforward processes in relation to the internal model when a repetition task involving vision and motion is given to participants. In the experiment introduced here, subjects watch "a number" displayed on the computer screen and simply push a button on the equipment corresponding to the same number. As the experiment is repeated over several trials, the feedforward control representation is strengthened in the internal model, and the ratio of the feedforward control to the feedback control rises. Based on an analysis of Response Times, the motion trajectories and the electroencephalographic (EEG) signals, we discuss the weighting of feedback and feedforward processes in the internal model.

2. MOTION INTERNAL MODEL

Figure 1 shows the concept of internal model. When a nonzero difference is present between the desired trajectory and the realized trajectory of the movement, the difference signal is transmitted to Purkinje cells in the cerebellum and controls both motion output and initiation time. In the forward component of the internal model, the output is controlled by motion so that the actual movement trajectory converges onto the target position as much as possible. In the inverse model, low-level learning is slow, but learning is performed so that the error between the position of the motion signal and the position of the actual trajectory of the movement decreases, so as to adjust the position of the actual movement using signals from the forward model.

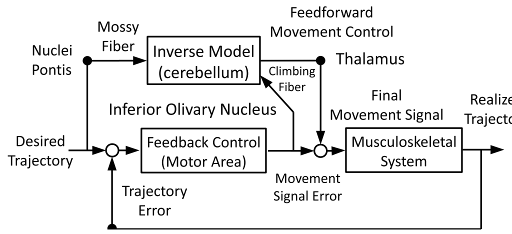

Figure 1: Structure of the internal model

3. EXPERIMENT

Figure 2 shows the experimental setup. A participant's head is held against a chin support device, and the computer screen is set to be $61cm$ in the front of the subject. A set of buttons (1, 2, 3) is placed at a distance of $46cm$ - $54cm$ in the front of the participant. After a 2-seconds resting time, the participant fixates a cross mark at the center of the computer screen followed by a number, also presented for 2 seconds. The participant is instructed to push the button whose number matches the number shown on the screen. The number displayed on the screen is repeatedly shown five times and is therefore referred to as a repetition pattern. Another pattern, called a non-repetition pattern, is displayed only three times. The set of presentations consisting of the five iterations of the repetition pattern and the three iterations of the non-repetition pattern is referred to as a presentation pattern. One trial consists in three repetitions of a presentation pattern, and the experiment is repeated over 7 trials. Participants consisted of five adults, including two men (early 20s, all right-handed) and three women (early 20s, all right-handed). Overall, we measured the motion trajectories of subjects as they pushed the buttons a total of 504 times, corresponding to 168 pattern presentations.

Figure 2: Experiment

Figure 3: Motion Sensors

We recorded subjects' Response Time and motion trajectory during each button push following the presentation of a number on the screen, and also simultaneously recorded electroencephalographic (EEG) activity. Figure 3 shows the positions of sensors used to measure acceleration and angular velocity (TSND121, ATR-Promotions Co. Ltd., sampling frequency: $100Hz$). The EEG signal was recorded at the following eight electrode locations: F_{p1}, F_{p2}, C_1, C_2, C_z, P_z, O_1, and O_2. Electrodes were placed according to the international 10-20 system using the EEG measurement device (AP216 Polymate-II, TEAC Corporation, sampling frequency: $200Hz$).

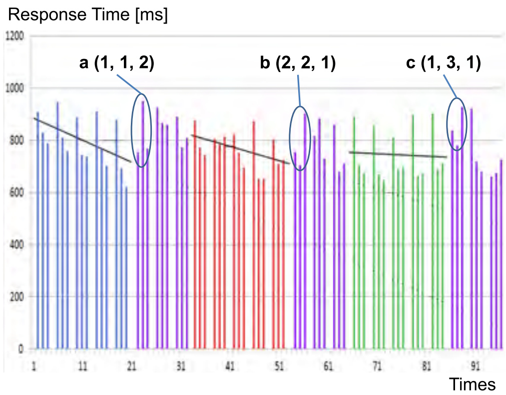

Figure 4: Response Time of the first pattern

4. MEASUREMENT RESULT

Figure 4 shows the result of the first trial of subject H. The vertical axis shows the Response Time (ms) for a subject to push a button following presentation of a number. We estimated a regression line for the Response Time using regression analysis. The gradient of the regression line for the first repetition pattern is steeper than the gradient for the second and third patterns, and the gradient becomes more shallow with the number of repetitions. We suggest that the phenomenon can be explained with the internal model as a switching from feedback to feedforward process occuring over multiple trial repetitions. The average Response Time of the first repetition pattern (1, 2, 3) is $731ms$, but the average Response Time of the non-repetition pattern a(1, 1, 2) continuing after the first repetition pattern is $824ms$. In addition, the average Response Time of the non-repetition pattern is $789ms$ and $848ms$ for the second and third trials, respectively. These average Response Times are larger than the corresponding averages of the repetition pattern for the second and the third trials, which are $745ms$ and $767ms$, respectively. In particular, the Response Time of the second number (number "1") of the non-repetition pattern is extremely large, approximating $950ms$. We suggest that this phenomenon can be explained in terms of a delay incurred during switching among feedback and feedforward processes in the Internal Model.

The vertical axis in Figure 5 shows the angular velocity (dps) of finger (S_1) along the Z axial dimension for the first pattern of subject H. Measurements corresponding to the repetition pattern are shown to the left of the vertical dashed line, whereas measurements for the non-repetition pattern are shown to the right of the dashed line. The negative and positive regions of the vertical axis correspond to clockwise and counterclockwise motion, respectively. At the second presentation of the non-repetition pattern, the movement recorded is first clockwise, which is similar to "2", but suddenly becomes counterclockwise. We suggest that this reflects switching processes in the internal model.

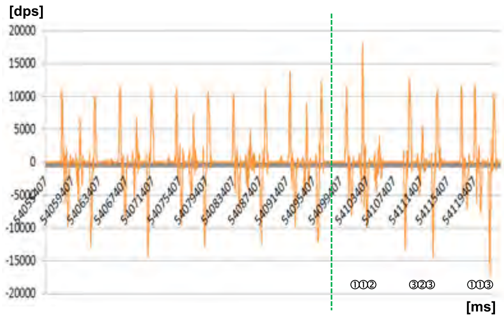

Figure 5: Angular Velocity of the First Pattern

Finally, we show an EEG result for subject H in Figure 6. It can be seen that the variance is smaller for the third and fourth repetition patterns. Learning thus occurs immediately over the course of a few repetitions of the pattern.

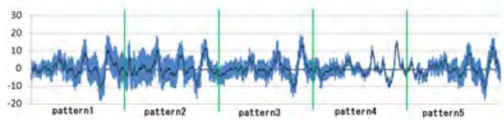

Figure 6: EEG of Repetition Pattern at FP1

5. REFERENCES

[1] M.Kawato and H.Gomi. A computational model of four regions of the cerebellum based on feedback-error learning, *Journal of Biological Cybernetics*, *68*, *2*, 95-103 (1992).

[2] H.Imamizu, T.Kuroda, T.Yoshioka, M.Kawato. Functional magnetic resonance imaging examination of two modular architectures for switching multiple internal models, *Journal of Neuroscience*, *24*, *5*, 1173-81 (2004).