



SOME CONCERNS ABOUT THE UTILIZATION OF MULTIPLE MODELS AND CONTEXT SWITCHING IN THE ADAPTIVE MOTOR CONTROL SYSTEM

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INTRODUCTION

- Reaching movements are typically performed in a straight line.
- Subjects are able to adapt to velocity dependent force field and return to a straight line.
- When the perturbation stops unexpectedly, after-effects are observed.
- These results were explained by an internal model of the external perturbation.

$$D(q) + E(q,t) = C(q_d,t) + \hat{E}(?)$$

Arm Dynamics Perturbation Nominal Controller Internal Model

- It was suggested that the brain can employ multiple models and switch between them according to a context.

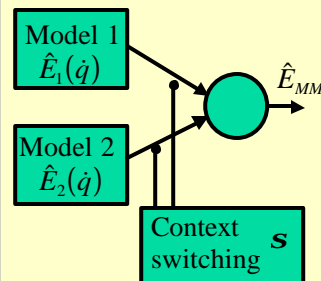
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The Multiple Models Hypothesis in the context of motor adaptation to external force perturbation

Suppose that the perturbation $E(q,t)$ alternates between two different perturbations $E_1(q)$ and $E_2(q)$ according to a predictable context $s = \{+1, -1, +1, -1, +1, \dots\}$

Strong Multiple Models Hypothesis: The CNS can extract multiple models from composite environment and then switch between them according to the context.

Weak Multiple Models Hypothesis: After sufficient exposure to multiple environments separately, the CNS can construct multiple models and switch between them according to the context.



In this study we consider the possibility that the internal model of the force perturbation can contain two switchable models

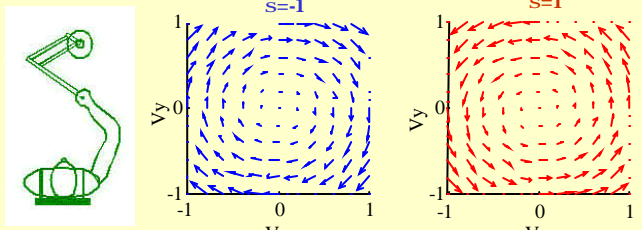
$$\hat{E}_{MM}(q,s) = \begin{cases} \hat{E}_1(q) & s = +1 \\ \hat{E}_2(q) & s = -1 \end{cases}$$

METHODS

- Five subjects performed reaching movements between three targets in four sessions at four consecutive days.
- The force field at each movement was one of two curl viscous fields (see Figure 2).
- In the first and in the fourth days the force fields alternated changing from right to left and from left to right after each movement. (4x168 movements at each day.)
- In the second day only one field was applied and in the third day only the other field was applied.
- In the early and in the late training of each day catch trials (i.e. trials without force perturbation) were introduced in 12 out of the 168 movements.

2 The Manipulandum and the force fields

$$f_x = s \cdot (-15) \cdot v_y \quad f_y = s \cdot (+15) \cdot v_x \quad s = \pm 1$$



- Direction Error (DE): Distance from a straight line calculated at the point of maximum velocity and multiplied by the direction of the error and by the direction of the force in the sequence:

Positive DE shows yielding to the field (wrong or under estimation).

Negative DE shows over estimation (or aftereffect at catch trial).



- Analyzing the errors as temporal signal was performed for each of the 6 movements separately. Single and dual, linear and nonlinear models were fitted to part of the data. (nonlinear is two values for d in the models below). Generalization error for an adjoined data part was calculated.

- Single Model: $z_{n+1} = a \cdot z_n + b \cdot s_n$
 y_n is the directional error (DE) $y_n = z_n + d \cdot s_n$
 z_n is an internal variable ("model")
 s_n is the direction of the force perturbation $\{\pm 1\}$

- Dual (Multiple) Model:

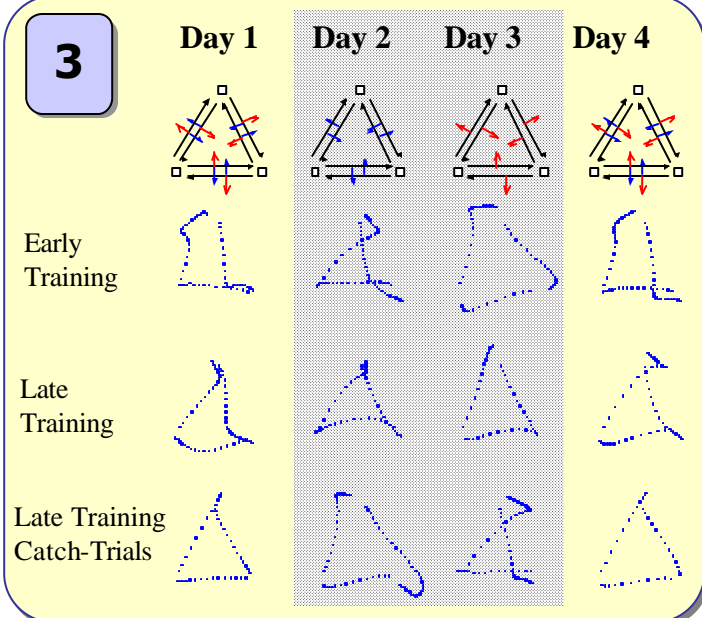
$$\begin{cases} z_{1n+1} = a_1 \cdot z_{1n} + b_1; & z_{2n+1} = z_{2n} & \text{if } s_n = +1 \\ z_{2n+1} = a_2 \cdot z_{2n} + b_2; & z_{1n+1} = z_{1n} & \text{if } s_n = -1 \end{cases}$$

$$y_n = \begin{cases} z_{1n} + d & \text{if } s_n = +1 \\ z_{2n} - d & \text{if } s_n = -1 \end{cases}$$

RESULTS

- Clear learning of each perturbation, but no evidence for multiple models and context switching on either the first nor the fourth day.
- Subjects remember the perturbation of the previous movement between the same targets.
- A parsimonious single model can explain the data as well or better than a multiple model.

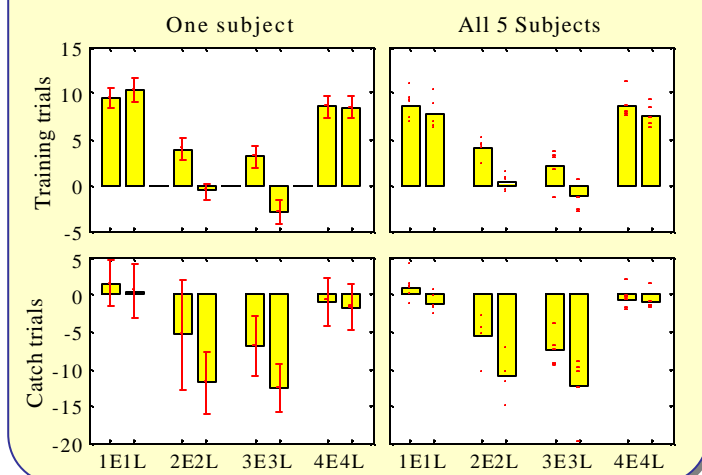
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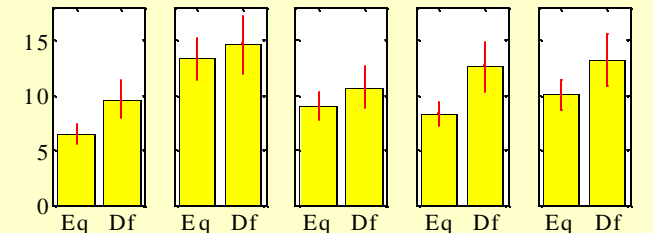
No evidence for multiple models even after the four days training.

Mean DE [mm] at Early(E) and Late(L) Training. Training trials (above) and catch trials (below).



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Evidence for learning attempt: RMS DE[mm] of the five subjects. Left (Eq): trials that experienced the same force field as the previous movement (between the same targets); Right (Df): opposite field at the previous movement.

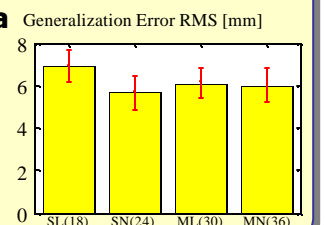


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Comparison of error models' capability to explain the data

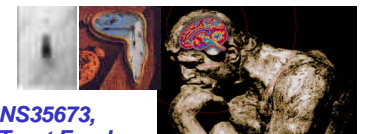
Generalization Error RMS [mm]

From left to right: Single linear, Single nonlinear, multiple linear, multiple nonlinear. The number of parameters in each model is indicated in the brackets.



DISCUSSION

- We tried to demonstrate the ability of the CNS to implement multiple models during motor adaptation to force perturbation.
- The experiment included clear learning of each model separately, sufficient time for memory consolidation and predictable context.
- Subjects were unable to construct two internal models and switch between them. A parsimonious single model can explain our data.
- The interpretation of many studies (such as the one about consolidation in motor memory) as an evidence for multiple switchable models should be reconsidered.
- The CNS mechanism that is responsible for motor adaptation to force perturbation demonstrates clear preference to a single state mapping of the perturbation over utilizing structures such as clocks, counter or switches that are the basis of artificial systems and many inspired models.



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