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Research Note

The relation between movement parameters and motor learning

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Abstract. In a recent paper, Flament et al. (1999) studied the process of learning to flex the elbow faster. They concluded from their data that time-related parameters (e.g. movement time) changed faster during learning than magnitude-related parameters (e.g. peak velocity) and discussed this finding in terms of neural substrates responsible for the apparently different learning mechanisms. In this paper, I will argue that finding different time constants does not imply different learning mechanisms and will give a theoretical example of the development of parameters during learning to move faster. Despite the fact that only one learning process is modelled, various kinematic parameters show different time courses of learning. The differences the model predicts are comparable with the experimental results.

Key words. Motor learning - Kinematics - Arm movement - Model - Human

Introduction

When one wants to study goal-directed human movements, single-joint movements of the elbow are a convenient prototype. In a recent paper, Flament et al. (*1999*) reported that for this task the time course of learning differed for different kinds of movement parameters. They found that timing-related parameters (e.g. movement time, MT) changed faster than magnitude-related parameters (e.g. peak velocity) and discussed this finding in terms of neural substrates responsible for the apparently different learning mechanisms. Are these different time constants indeed caused by different learning mechanisms, or are they caused by the mathematical relationship between these parameters?

When subjects halve their MT, without changing the relative time-course of the movement, they double their speed, and quadruple their acceleration (and deceleration). Two questions will be addressed regarding the development of these magnitude-related parameters during learning: firstly, whether the development of these parameters is also exponential when the MT decreases exponentially; secondly, whether the development of these parameters is characterised by the same time constant as the development of MT. Flament et al. (*1999*) based the interpretation of their results on the assumption that the answer to both these questions is "yes". Using a hypothetical single process of learning to move faster, the answer to both questions is proved to be "no".

Model calculations

The model was a simplified description of the task used by Flament et al. (1999). They studied 50° movements, which subjects learned to perform faster during 40 blocks of learning (10 trials each). The MT decreased exponentially from about 0.8 to 0.4 s, with a time constant of 3.68 blocks. This exponential development of MT during learning is shown in Fig. 1A, given by the equation:

$$\mathrm{MT}=0.4(1+e^{-t/3.68}) \quad (1)$$

where t is the number of blocks.

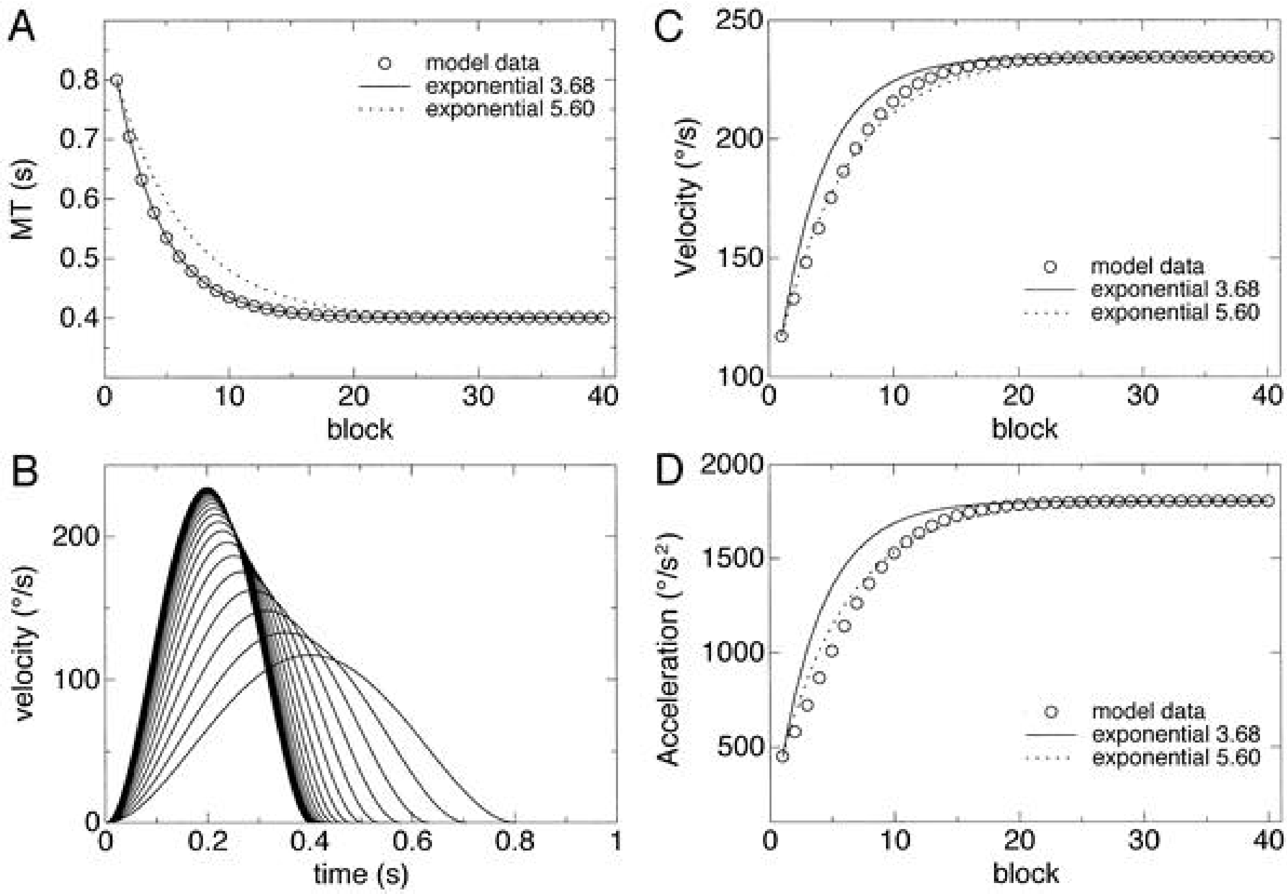

Fig. 1A-D. A model for learning to move twice as fast as normal. The movement times reduce exponentially from 0.8 s to 0.4 s, with a time constant of 3.68 blocks. **A** The development of the movement time (*circles*). The *continuous lines* show exponential functions (two different time constants), with the same initial and final values as the model data. **B** Velocity profiles of 40 model movements. Each movement is representative of a learning block. **C** The development of the peak velocity. **D** The development of peak acceleration

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To simulate faster movement, without any other change in the movement, one has to assume a relationship between MT and movement kinematics. The choice of this relationship is not important for the argument here. It was assumed that the movements during learning are minimum jerk movements (Flash and Hogan 1995). The peak velocity and acceleration of minimum jerk movements are a function of MT and movement distance (*l*):

$$v_{peak} = \frac{15\,l}{8\,MT};\ a_{peak} = \frac{10\,l}{\sqrt{3}\,MT^2} \qquad (2)$$

As the task in the experiment by Flament et al. (1999) was to move over a fixed distance *l* (50°), the assumption was that this parameter did not vary considerably during learning. The MT was thus the only input of the model that changed during learning. The development of peak velocity and peak acceleration during exponential learning of faster movement is plotted in the right part of Fig. 1. It is clear that the curve with the time constant of the change in MT (3.68 blocks) is not a good fit of the model data. This is also what Flament et al. found for their real data. Their mean best-fitting time constant (for acceleration, deceleration and velocity; about 5.6 blocks) fits the model data much better. When fitting an exponential function to the model data, the time constants 5.2 blocks for peak velocity and 6.0 blocks for peak acceleration were obtained. These values correspond quite accurately to the time constants found in the experiment of Flament et al. (1999).

However, also using these time constants, an exponential function did not reproduce the development of magnitude-related parameters in the model very well. Especially the development of acceleration clearly followed a systematically nonexponential time course during learning: it changed more slowly in the first few blocks and faster in the later blocks. The exact formulas for the development of these parameters explain why. Combining the exponential development of MT (Eq. 1) with the formula for the peak velocity and peak acceleration (Eq. 2) yields:

$$v_{peak} = \frac{75}{16}\,\frac{l}{\left(1+e^{-t/3.68}\right)};\ a_{peak} = \frac{125}{2\sqrt{3}}\,\frac{l}{\left(1+e^{-t/3.68}\right)^2} \qquad (3)$$

It is clear that these are not simple exponential functions.

Discussion

The model showed that if one kinematic parameter changes exponentially during learning, other kinematic parameters do not show the same behaviour. When fitting exponential functions to the development of these parameters, the fit for each parameter will result in a different time constant.

To model learning, two choices were made that merit some discussion. It is not self-evident which parameter develops according to an exponential function in experiments such as the one by Flament et al. (*1999*). I chose the rate of change of MT to be exponential. However, if one of the other parameters had been chosen to develop exponentially during learning, a similar reasoning shows that the other parameters would not develop exponentially. Therefore, fitting exponential functions to the development of the various parameters will yield different values for the time constant. The choice for a minimum-jerk description of movements is not crucial either. It is a relatively simple model for a fixed relationship between MT, peak velocity and peak acceleration, which yields quite realistic velocity profiles. Any model that preserves the shape of the velocity profile under scaling in time yields exactly the same time constants. If the velocity profile changes during learning, slightly different time constants may be found. However, any kinematic description of movements over a fixed distance will predict that the peak velocity is roughly proportional to the inverse of MT, and that the peak acceleration is roughly proportional to the squared inverse of MT (Nelson *1983*). The time constants for the development of these parameters will thus be different from each other.

In this paper, I argued that finding different time constants does not have to imply different learning mechanisms and gave a theoretical example of the development of the process of learning to move faster. Despite the fact that only one learning process was modelled, various kinematic variables showed different time courses of learning. This means that a single learning process is characterised by several different time constants.

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