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Error Generalization as a Function of Velocity and Duration

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Introduction

While making reaching movements we must plan the direction, distance, speed, and magnitude of the forces needed to achieve a goal. In resent years several researchers have suggested that there is an internal model within the motor control system, and this internal model is responsible for transforming desired movements, or goals into motor patterns that accomplish the goal.

It has been theorized that our motor system employs a set of motor primitives that can be summed via different weightings to produce a wide variety of movements. Recently it has been suggested that there exists a hypothetical set of such motor primitives that function by associating a given force with a given velocity (Thoroughman and Shadmehr 2000; Donchin et al. 2003). Consequently when subjects learn to actuate a robotic manipulndum in the presence of a perturbing force field we were able to use a simple **time series model Y(n) = D*F(n) - Z(n) with Z(n+1) = Z(n) + B*Y(n)** to predict the pattern of errors Y(n) made by the subjects with the added constraint that all movements were about the same speed, duration (500 msec) and distance (10 cm). This model states that the “error” on the nth movement Y(n) is the difference between the **internal models expectation Z(n)** and the true force experienced D*F(n), where **D is a compliance term that translates force into displacement**.

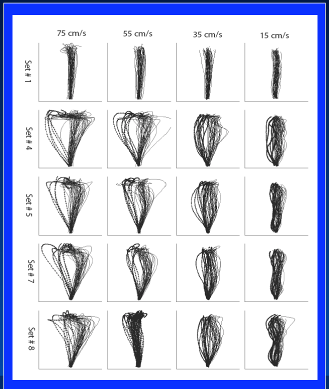
In the present study subjects made reaches to a visual target 15 cm away with a maximum velocity of 15, 35, 55 or 75 cm/sec cued in a pseudorandom order via a minimum jerk trajectory viewed before each movement. Subjects experienced a viscous curl field with catch trials (approximately 16% of reaches). We found that a simple simulation (adaptive controller) that is composed of Gaussian basis elements in velocity space reproduces the same type of generalization seen for the human subjects as we have previously shown for movements made in different directions (Donchin et al. 2003) extending the set of movements that such a model can represent, and that the simple time series model seen above accounts very well for both the simulation results as well as the humans with an r-squared value of 0.92 between the simulations data and the subjects. With the generalization function B being indistinguishable between the simulation data and the subjects’ data using Gaussians with sigmas of about 15cm/sec as in our previous work. **In the final target set all of the 55cm/s movements were catch trials.** This was done in order to determine if the subjects could quickly dissociate their internal model for this speed group. Only the author with full knowledge of the task could do so.

Results:

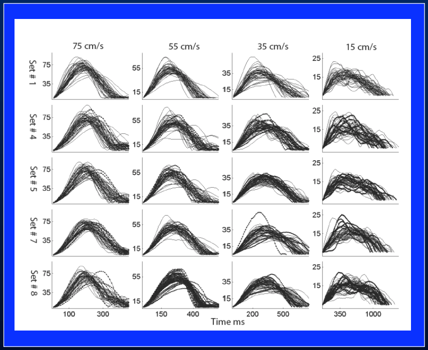
The time series model was able to capture the dynamics of the human subjects data r = .95. A simulated adaptive controller made up of Gaussian basis functions in velocity space was fit well by the timer series model and correlated very well with the human date r = .96. The generalization function (B) was indistinguishable between the simulation and the humans. It was necessary to normalize the simulations error by the duration of the movement for it to represent the subjects learning pattern.

Methods:

The general methods are as those presented in Donchin et al 2003. Our Error proxy was the perpendicular displacement taken at the maximum velocity point in the movement. The general form of the time series model is show in the introduction. Our simulated adaptive controller was similar to previous work and consisted of a tessellation of Gaussian primitives in velocity space sigma 14cm/s). The adaptive controller learned via gradient decent. An important difference between this and our earlier work is that we scaled the controllers integration of error by the duration of the movement, otherwise the simulation did not learn in a manner keeping with the human subjects.

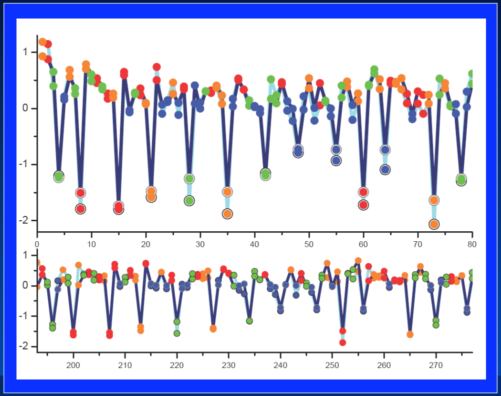


Raw Kinematics from a typical subject making 15 cm reaches. Set 1 is in the Null field and sets 4-8 are in a Velocity dependant curl field. All 55cm/s reaches in set 8 are catch trials. Below we have plotted the speed profiles for the movements made in fig 1.

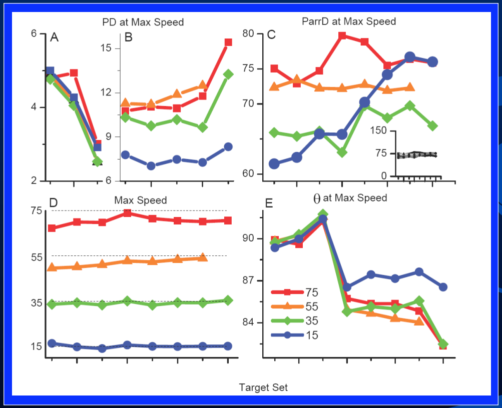


Set #	1	2	3	4	5	6	7	8
15 cm/s	48	48	48	7	7	10	7	10
35 cm/s	48	48	48	12	12	12	9	12
55 cm/s	48	48	48	8	8	7	7	48
75 cm/s	48	48	48	5	5	6	9	6
N	13	9	5	13	11	12	12	12

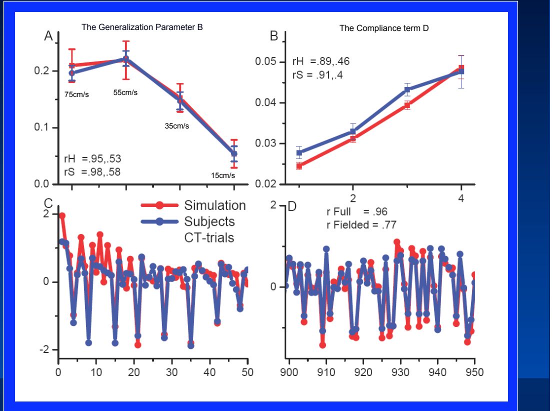
Table 1: This table outlines the target set (top row) structure and the number of subjects (bottom row) that performed each target set. The four velocity groups are labeled in the left column, and the body of the table is the number of Null Fielded movements made for the given vel group during the given target set. Thus we see that the first three target sets had 48 null movements for each vel group, and the last target set consisted of all Null movements for the 55 cm/s group, but mostly fielded movements for the other groups as there are always 48 movements at each vel in each target set one can easily determine the number of fielded movements.



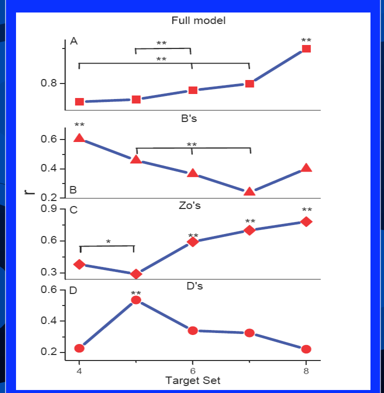
Time series of Perpendicular displacements from the average of the subjects (light blue) and the Output of the Time series model. The movements are color coded corresponding to the speed groups 75, 55, 35 and 15 cm/s as red, orange, green and blue. Ct trials deviate toward the bottom of the Fig.



A. Is the PD at the maximum speed for the Null fielded sets followed by the fielded set in B. C shows the Parr D for each target set. The inset gives an indication of just how close to the mid point of the movement the subjects are at their maximum Velocity point. Notice that the slowest group continues to modify its max Vel position converging on the mid point of the movement. D. The average maximum velocity for each target set, note that the faster Vel groups are consistently slower than the target speed While still adhering to the task criterion that allow the subject to be 5cm/s slower than the target. We found little difference between the PD and Theta.



A. The average B from the timer series model fit to the subject’s data and the simulation (adaptive controller). I have also included the mean correlation coefficient between the mean subject’s data and the time series model fits to that data (rH) as well as the time series model fits to the simulation data (rS). The first of the two numbers is for the full model and the second is for the *B*’s looking only at the fielded movements. Likewise plotted In panel B are the D’s as well as the corresponding r values for all of the data and then just the fielded. Plotted in C and D are the average PDs for the Subjects as well as from the adaptive controller with the r values between the two data sets.



Partial r values for each of the fielded target sets first for the Full model (A) followed by the other parameters in the time series model. These r values are for the fielded movements only, not including the catch trials.

Conclusions:

1.) Trial-by-trial motor learning in subjects making reaches at different velocities can be described by an adaptive controller that learns via Gaussian basis elements in velocity space.
2.) The simulation’s learning only resembled the humans if we normalized the error function it used to learn by the duration of the movement indicating that humans in some manner scale the error experienced during reaches at different speeds, or simply have different thresholds for what is considered an error at the different speeds of movement.
3.) It is possible to separate the internal models based on speed grouping, but this apparently requires explicit knowledge of the task, or perhaps cues to be provided as only the author was able to do so during the 8th target set where all 55cm/s reaches were catch trials.