Prespecified After-effects Elicited from Robotic Force Fields

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INTRODUCTION

Robots have a promising future in the area of training, particularly in neuro-rehabilitation. However, the most effective training algorithm has yet to be determined.

Here we capitalize what is known about implicit learning in motor adaptation:
- Repeated exposure to a force field leads the original movement being recovered.
- Subjects do this by canceling the forces of the field.
- When the disturbing force field is unexpectedly removed, subjects exhibit after-effects. (Shadmehr & Mussa-Ivaldi, 1994).
- Subjects learn an internal model of the robot field that approximates the perturbing field’s equation. (Conditt & Mussa-Ivaldi, 1997).
- Subjects can also generalize to new movements in a region near where the training occurred. (Gandolfo et al. 1996).
- Neuromechanical models can predict after-effects (Shadmehr & Mussa-Ivaldi, 1994).

Therefore, it should be possible to design force fields that induce desired after-effects.

In this initial study, we address 1) whether it is possible and 2) we compare two possible approaches.

METHODS

Goal: For at least the initial part of the movement (first 200 ms), cause the subjects to move along a desired trajectory unknown to them, \( x_p \), as an after-effect.

Two “field design” approaches:

1. **Direct** Approach (8 subjects):
   - The robot learns the forces necessary to move the subject along a desired trajectory, \( F(t) \), intermittently adjusting \( F(t) \), following the online learning rule:
     \[ F(t) = F(t) + h(x(t) - x_d(t)) \]
   - The robot applies the opposite forces for training.

2. **Modeling** Approach (4 subjects):
   - The robot perturbs the subject.
   - **System Identification**: Fit a model like (Shadmehr & Mussa-Ivaldi, 1994), but consisting of a linear combination of many different arm-and-controller models (Patton & Mussa-Ivaldi, submitted). (Figure 2)
   - The model calculates the forces necessary to move the subject along the desired trajectory, reverses them (in torque space), and then fits them to an array of regional force fields.
   - Subjects were not told about or shown the desired movement.

RESULTS

HYPOTHESES:

Do we get desired after-effects?

\( H_0 \): After-effect trajectories are no different than baseline movements. Rejected.

\( H_1 \): Aftereffect trajectories are no different than desired trajectories. No.

Comparing approaches:

\( H_0 \): After-effect trajectories are closer to desired when the modeling approach is used. No.

SUMMARY & CONCLUSIONS

- It is possible to design force fields that shift trajectories towards desired movements. Hence these approaches show great promise for the rehabilitation of movement deficits in patients.
- Surprisingly, the direct approach is best -- a model that simply considers feedforward and LTI neuromechanical impedance (as in Shadmehr & Mussa-Ivaldi, 1994) is not enough.
- This “implicit learning” approach is an alternative to training methods based on the explicit specification of the desired movement to the learner.

References


See http://manip.smpp.nwu.edu for more.

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