Robot-assisted learning of redundant tasks

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INTRODUCTION

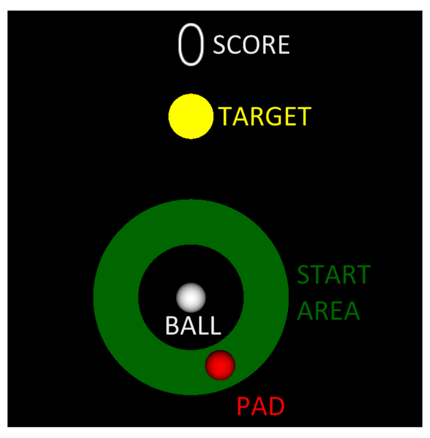
Robots might be used to promote the acquisition of novel motor skills, by guiding the trainees to experiment the correct movements or by preventing them from performing incorrect ones (the 'guidance' hypothesis). However, it is unclear how to shape guidance to make learning greater and faster.
One particularly challenging situation is that of **redundant tasks**, in which different movements lead to the same task performance.
How does learning proceed, and what should the robot do in this case?
Here we explore this issue in the context of two tasks:

1. Putting
2. Handwriting transfer from dominant to non-dominant hand

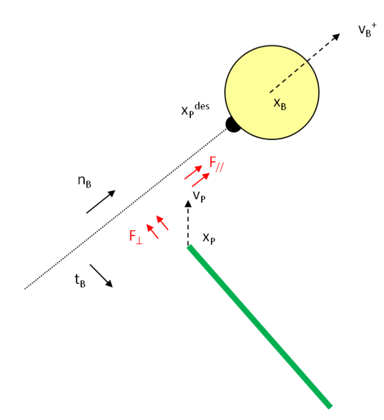
We investigate the way humans improve their performance by exercising each task, with and without the assistance of a robot.

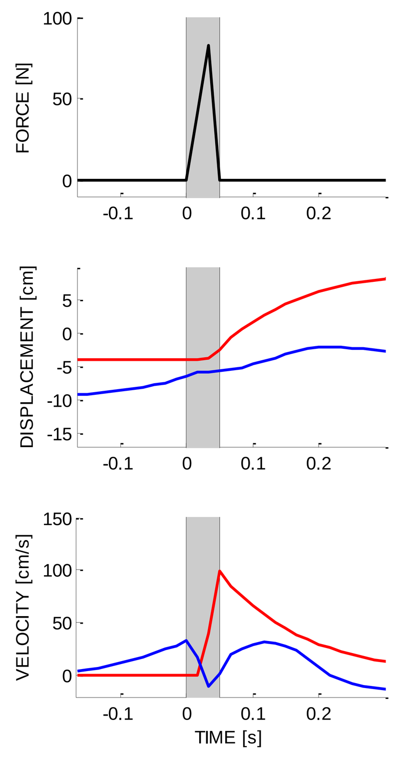
EXPERIMENT 1: PUTTING

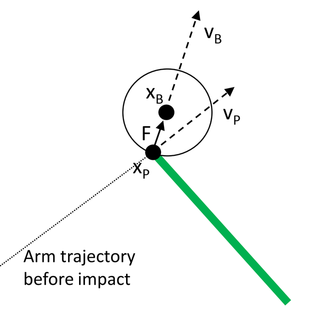
Task. Putting consists of gently hitting an object (e.g. a 'ball') by means of a tool (the 'pad', e.g. the golf putter) to move it to a desired final position. Successful performance is determined by an accurate adjustment of pad velocity at impact. Putting is a redundant task, in the sense that the same final position of the ball can be obtained by different combinations of pad velocity and active force. A virtual environment, involving a planar robot manipulandum and a computer screen was used to simulate the physics of the ball and the force exerted on the pad during impact.
Assistance. In one subjects group (**control**) the robot generated no assistance. In another group of subjects (**assisted**), the robot generated forces aimed at directing pad movements toward a target position and velocity. In the assisted groups, assistance was allowed to gradually decay according to an exponential law.
Data analysis. We looked at subjects' performance (and its evolution with exercise) at several levels of description, from the final error (distance between final ball position and center of the target area) to the ball velocity just after impact, to the pad velocity before impact. We looked at both mean value and variability, by distinguishing between task-relevant and task-irrelevant quantities.



Scheme of assistance:

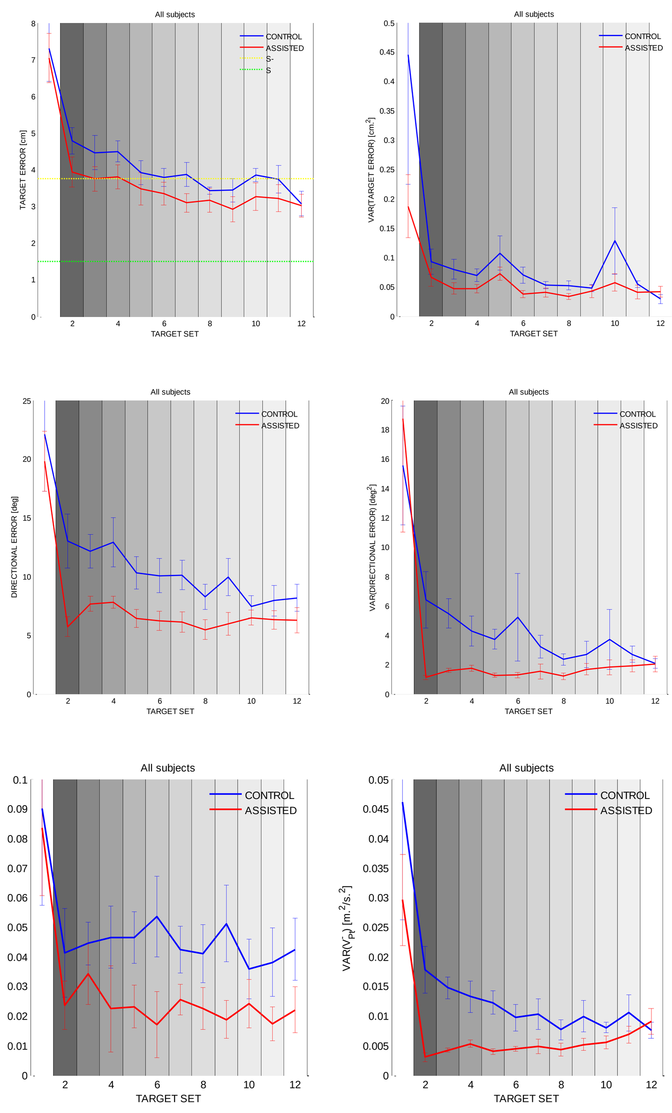


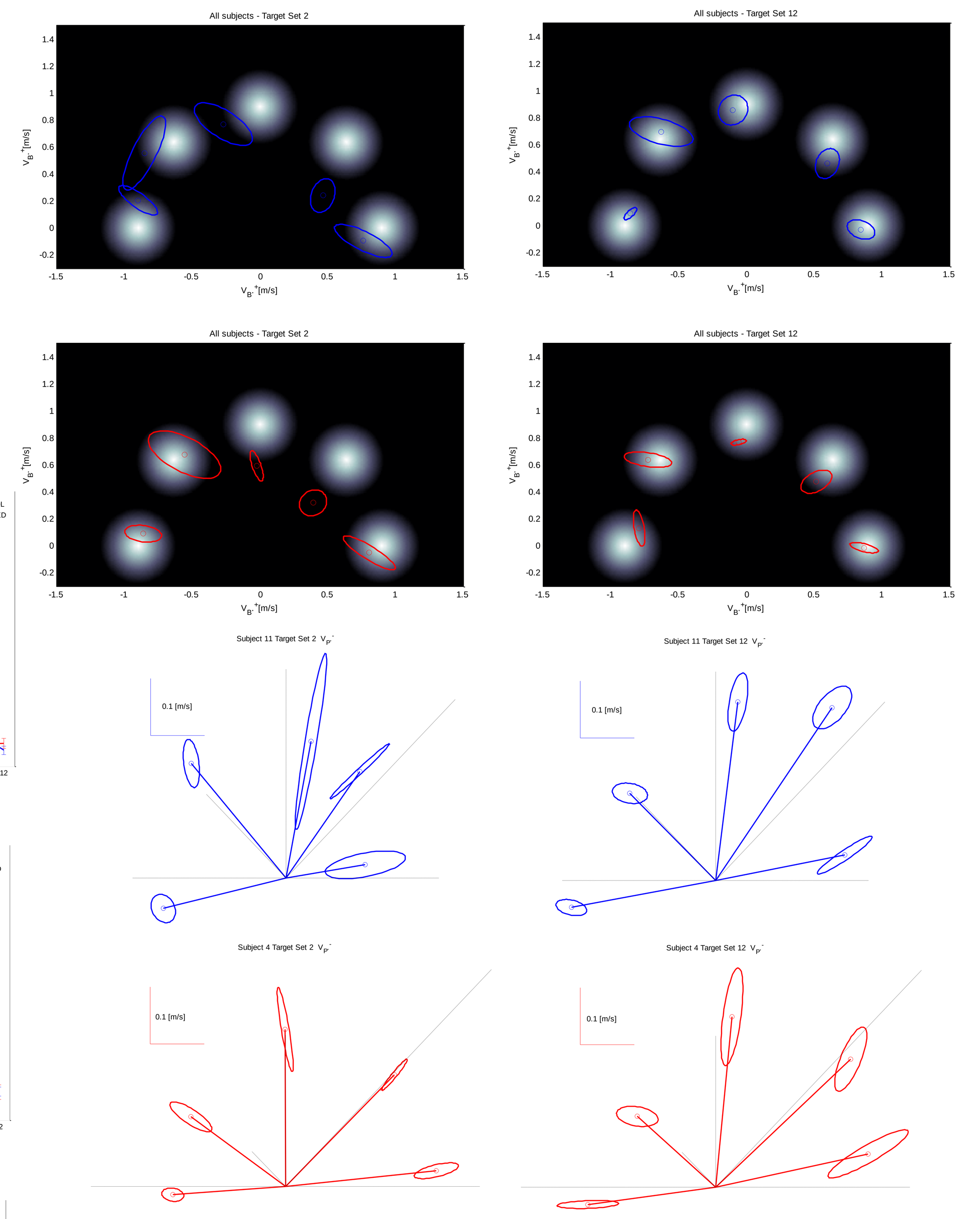




From conservation of momentum and conservation of energy (elastic impact):

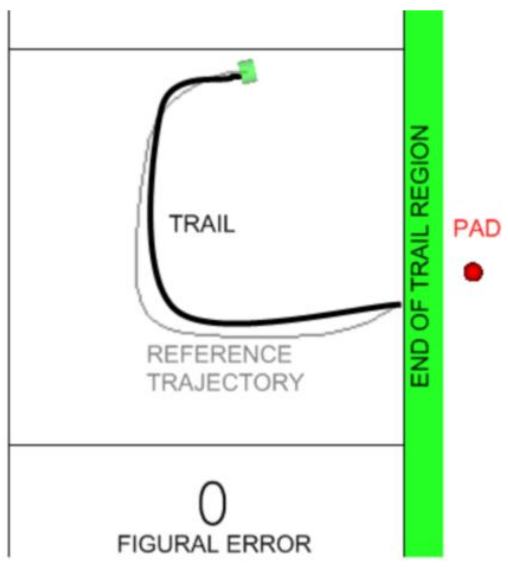
$$x_B(\infty) = x_{B_0} + \frac{m_B}{b}\dot{x}_B^+ = x_{B_0} + n_B \cdot \frac{2}{b}\cdot(m_B^{-1} + n_B^T M_{P_x}^{-1} n_B)^{-1}\cdot n_B^T \cdot \dot{x}_P^-$$





EXPERIMENT 2: HANDWRITING TRANSFER

Task. Subjects must learn to write characters of increasing complexity with their non-dominant hand. Handwriting is redundant, in the sense that characters that can be interpreted as the same can be obtained in many different ways. Subjects were first required to draw selected characters with their dominant hand. Then they had to reproduce these same samples with their non-dominant hand.
Assistance. In one subjects group (**control**) the robot generated no assistance. In other subject groups, the robot generated assistive forces, aimed at either tracking the trajectory recorded (**trajectory guidance**) or at staying close to the recorded path (**path guidance**). These schemes of assistance imply the selection of one specific 'desired' trajectory (or path).
Data Analysis. We focused on the structural aspects of the trajectory and on their trial-by-trial variability.

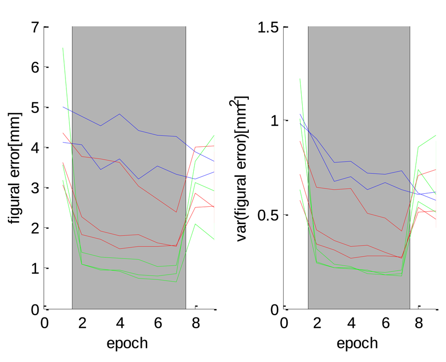


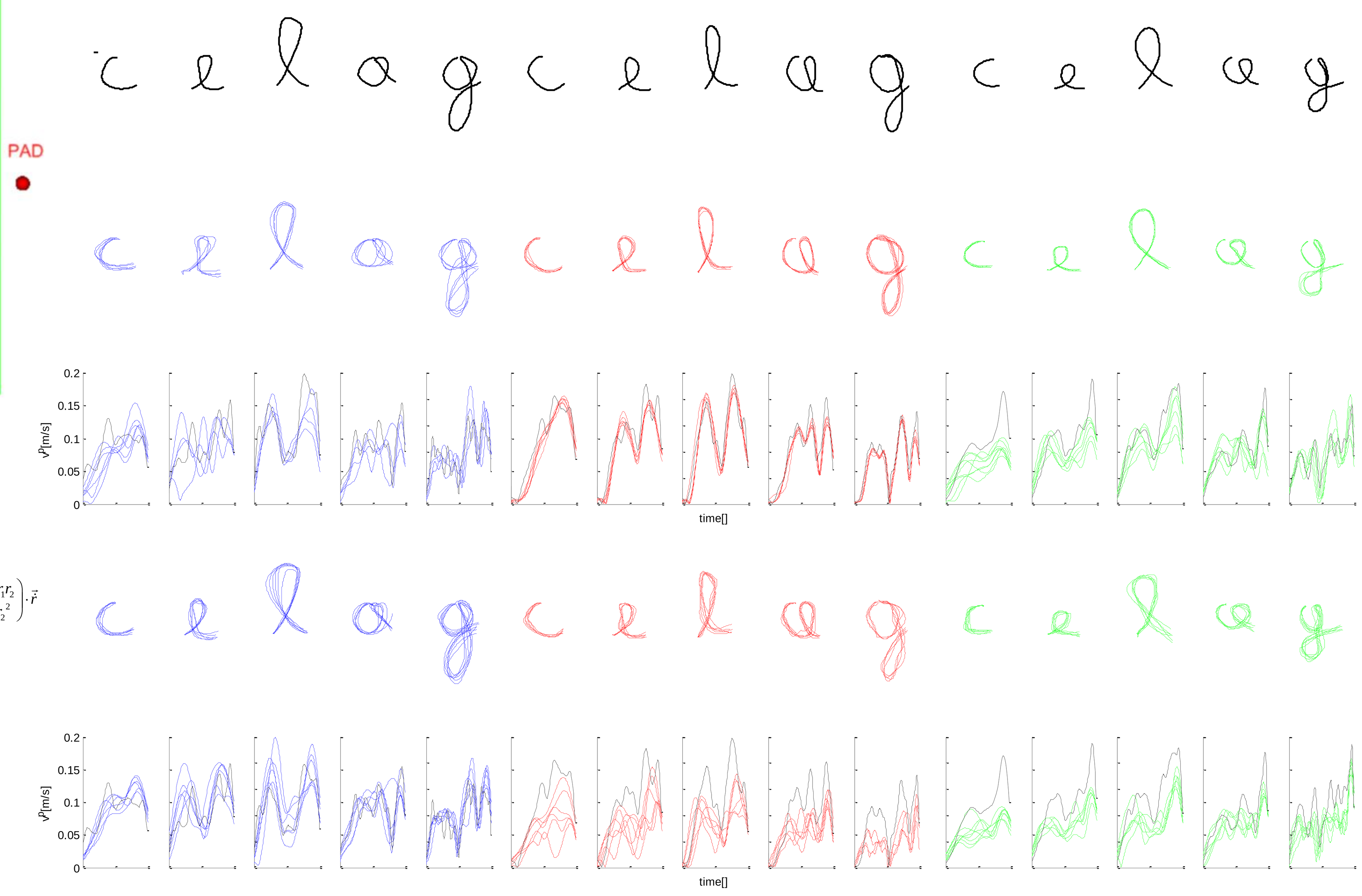
Trajectory guidance:

$F = k(\vec{r}_c(t) - \vec{r}) - u\cdot\dot{\vec{r}}$

Path guidance:

$F = k(|curv(\vec{r}_c)|)\cdot\begin{pmatrix} r_y^2 & -r_x r_y \\ -r_x r_y & r_x^2 \end{pmatrix}\cdot(\vec{r}_c - \vec{r}) - u(|\vec{r}_c|)\cdot\begin{pmatrix} r_y^2 & -r_x r_y \\ -r_x r_y & r_x^2 \end{pmatrix}\cdot\dot{\vec{r}}$





CONCLUSIONS

Both control and assisted subjects gradually learned to perform the task. However, that developed strategies that differed from the 'desired' ones, encoded in the schemes of assistance.
In the case of putting, model simulations suggest that the learned strategies are near-optimal, in the sense that they result from a trade-off between attaining task goals and minimizing motor effort.
We suggest that assistance should ideally reflect these optimality criteria, and as such to focus on the task-relevant aspects of the movement.

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