HUman behavioral Modeling for enhancing learning by Optimizing hUman-Robot interaction
FP7-ICT-231724

The humour project

www.humourproject.eu

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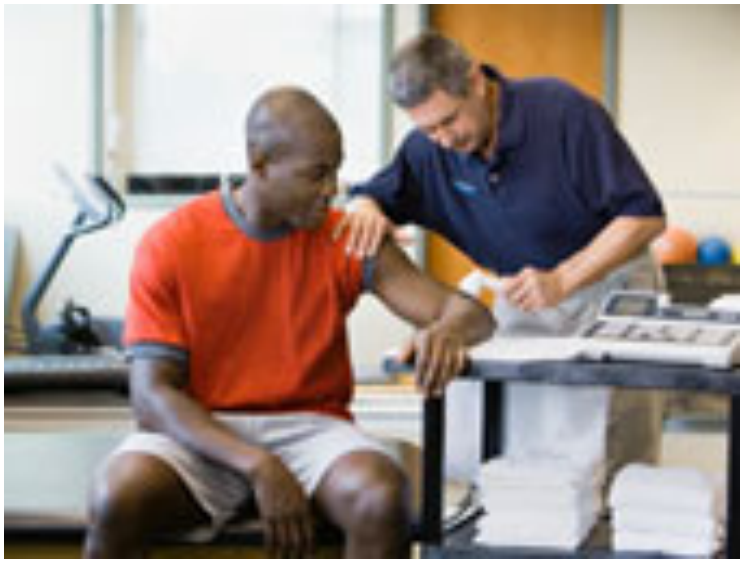
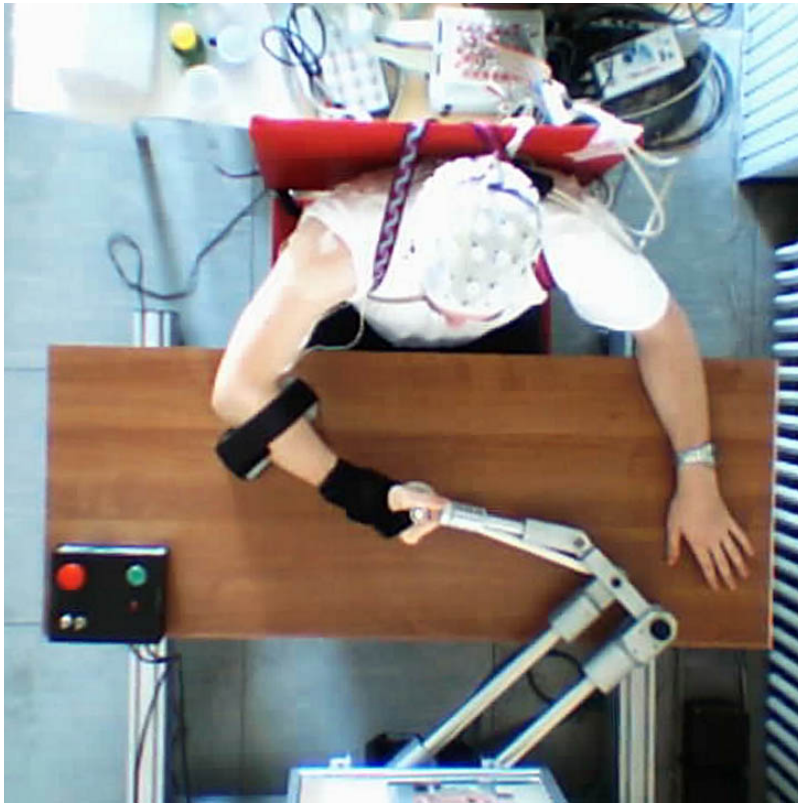
Motor skill learning through physical assistance



The humour concept: robots and BCIs to facilitate motor skill learning and neuromotor recovery



- **Use robots to study** physiological basis of learning through physical interaction
- **Test on different typologies** of motor skill learning tasks
- **Integrate with BCI technology** to regulate interaction through neural correlates of motor commands, learning, attention
- **Build robot trainers** that support/ facilitate learning
- **Validate** in motor skill learning and rehabilitation domains

Outline

1. Science

- Optimal interaction in motor skill learning
- Human-human interaction
- An haptic BCI

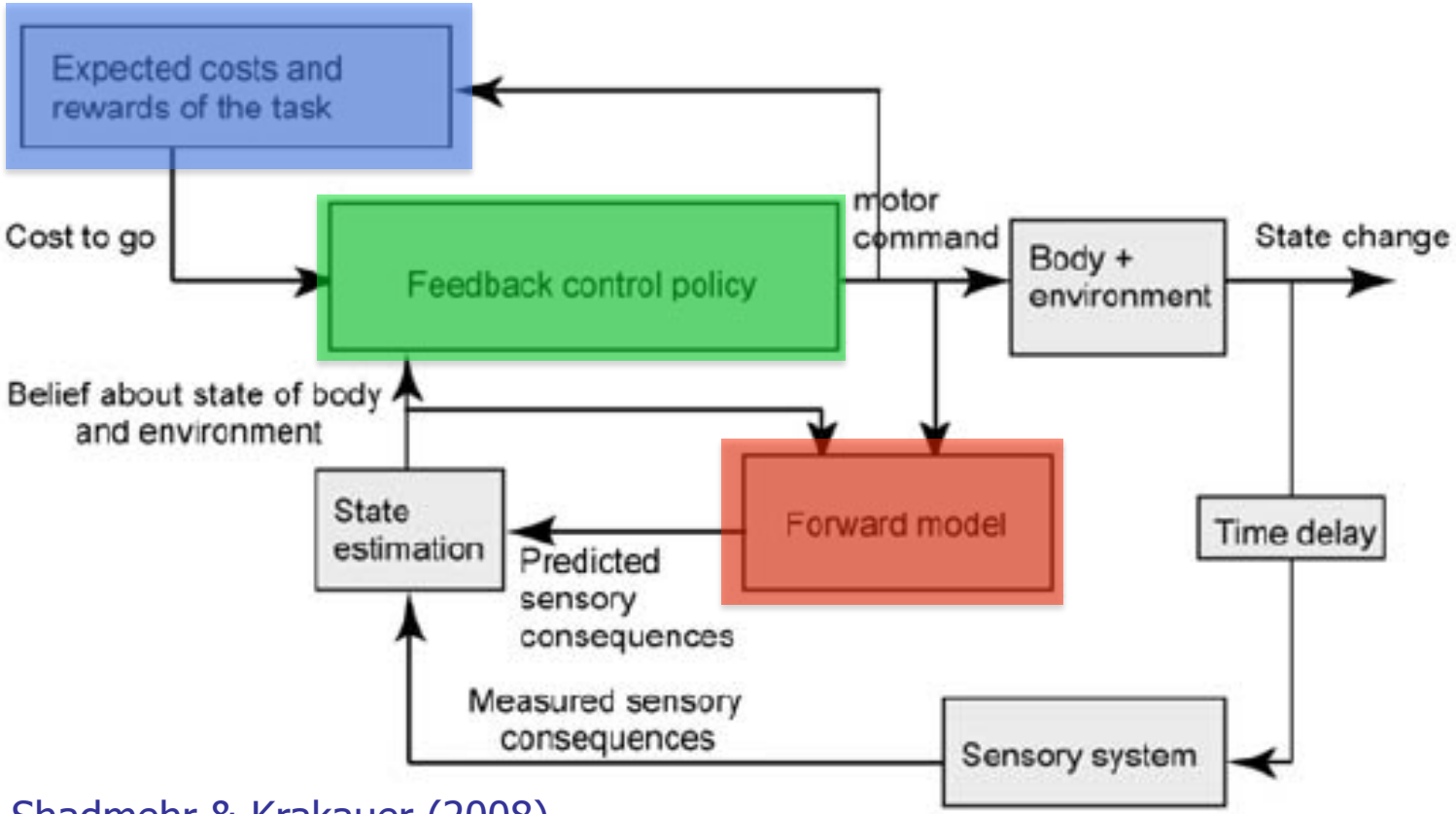
2. Technology

3. Clinical practice

Can haptic guidance facilitate the acquisition of motor skills?

If only I could experience the golf swing of Tiger Woods, then I could rapidly improve my own swing?

(Reinkensmeyer & Patton 2009)



Shadmehr & Krakauer (2008)

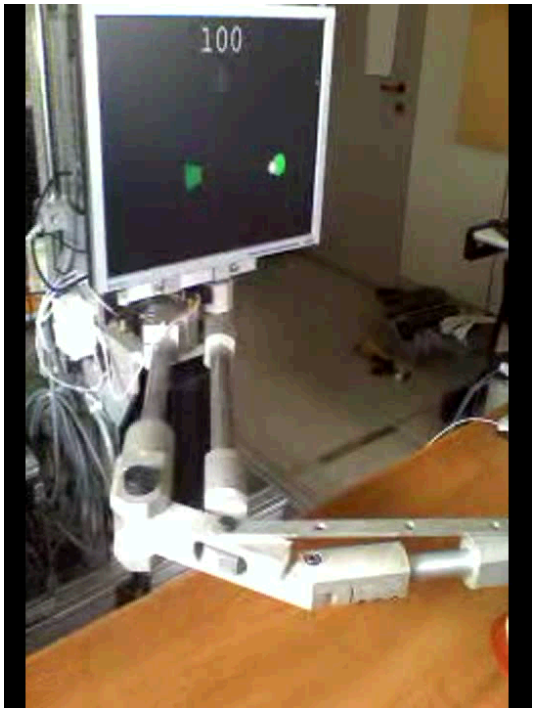
- **Kinematics/dynamics learning:** acquire/adjust an internal model
- **Skill learning**: learn action-value mapping
- **Strategy learning**: decide among motor-equivalent strategies
- Adaptation + skill learning: most real-life situations

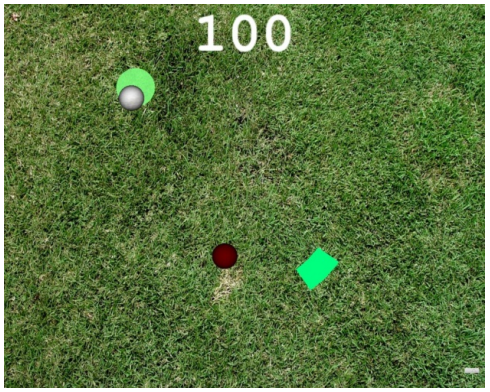
Different types of motor learning problems likely require different types of guidance

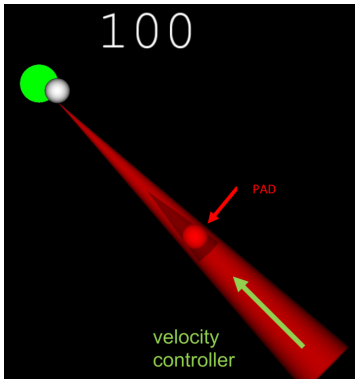
Guidance experiments

Heuer, H. & Rapp, K.M. (2011). Active error corrections enhance adaptation to a visuo-motor rotation. Experimental Brain Research, 211: 97-108
Lüttgen, J. & Heuer, H. (in press). The influence of haptic guidance on the production of spatio-temporal patterns. Human Movement Science

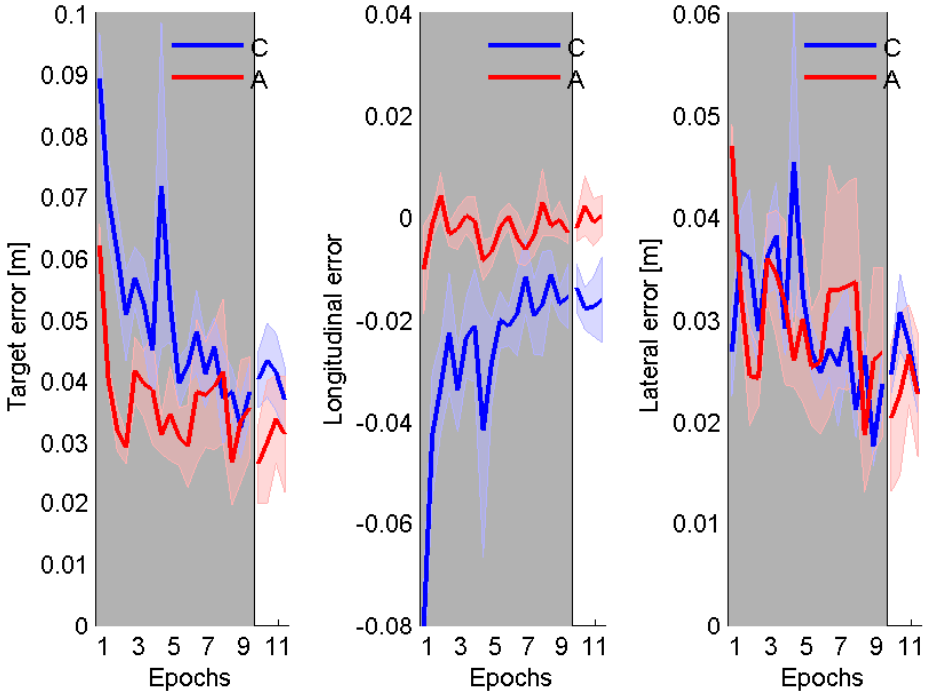
‘Tool‘ manipulation: putting







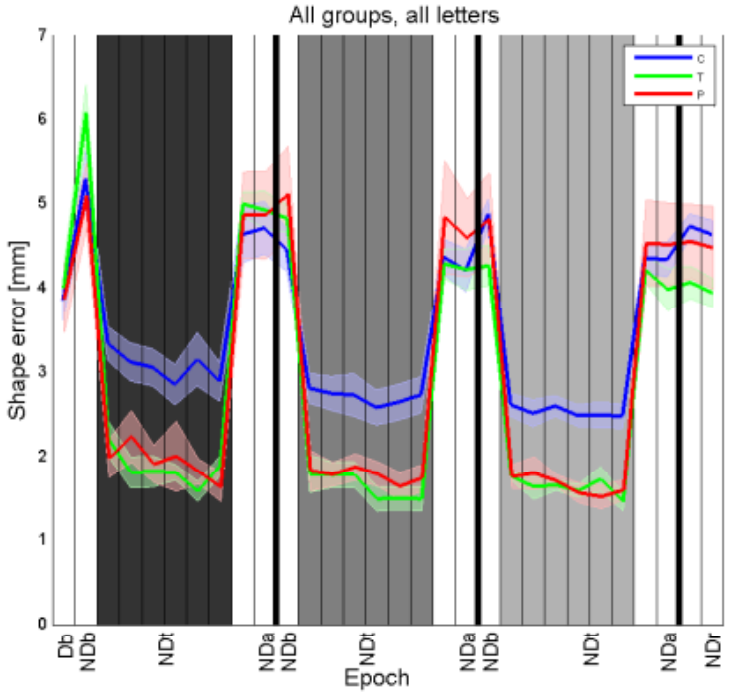
- Guidance significantly affects longitudinal error (velocity control)
- Guidance does not affect lateral error (position control)



Intermanual transfer of cursive handwriting

- **Task**: write single cursive letters with non-dominant hand

- Three guidance modalities:
  - **Visual assistance (C):** displaying reference template
  - **Path guidance ('teach the shape' ,P)** : error clamping around the reference template
  - **Trajectory guidance ('teach the movement' ,T):** pulling toward reference trajectory



Basteris A., Bracco L., Sanguineti V. (in press) Robot-assisted intermanual transfer of handwriting skills. Human Movement Science.

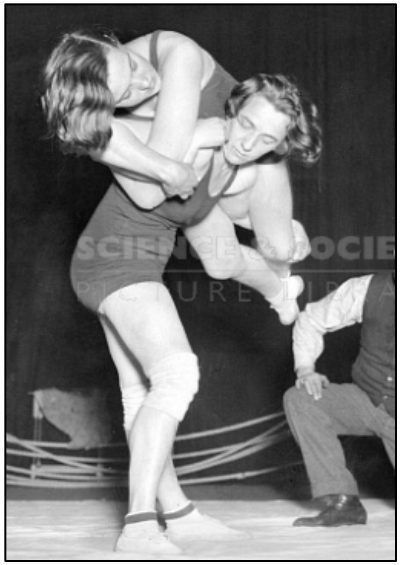
Haptic guidance in motor skill learning: summary

- **Beneficial:**
  - Haptic demonstration of correct movements (e.g. learning of dynamic movement characteristics)
    → *facilitation of imitation learning?*
  - Error amplification (e.g. learning of dynamic transformations)
    → *facilitation of error-based learning?*
  - Guided exploration of solution space (e.g. learning discrete motor strategies)
    → *facilitation of strategy search?*

- **Detrimental:**
  - Error reduction or prevention of active error corrections (e.g. learning of kinematic transformations)
    → *inhibition of error-based learning?*
  - Conflict between strategies of robot and (experienced) learner (e.g. learning continuous motor strategies)
    → *interference of new and established strategies?*

Beyond guidance: a theory of human-human interaction

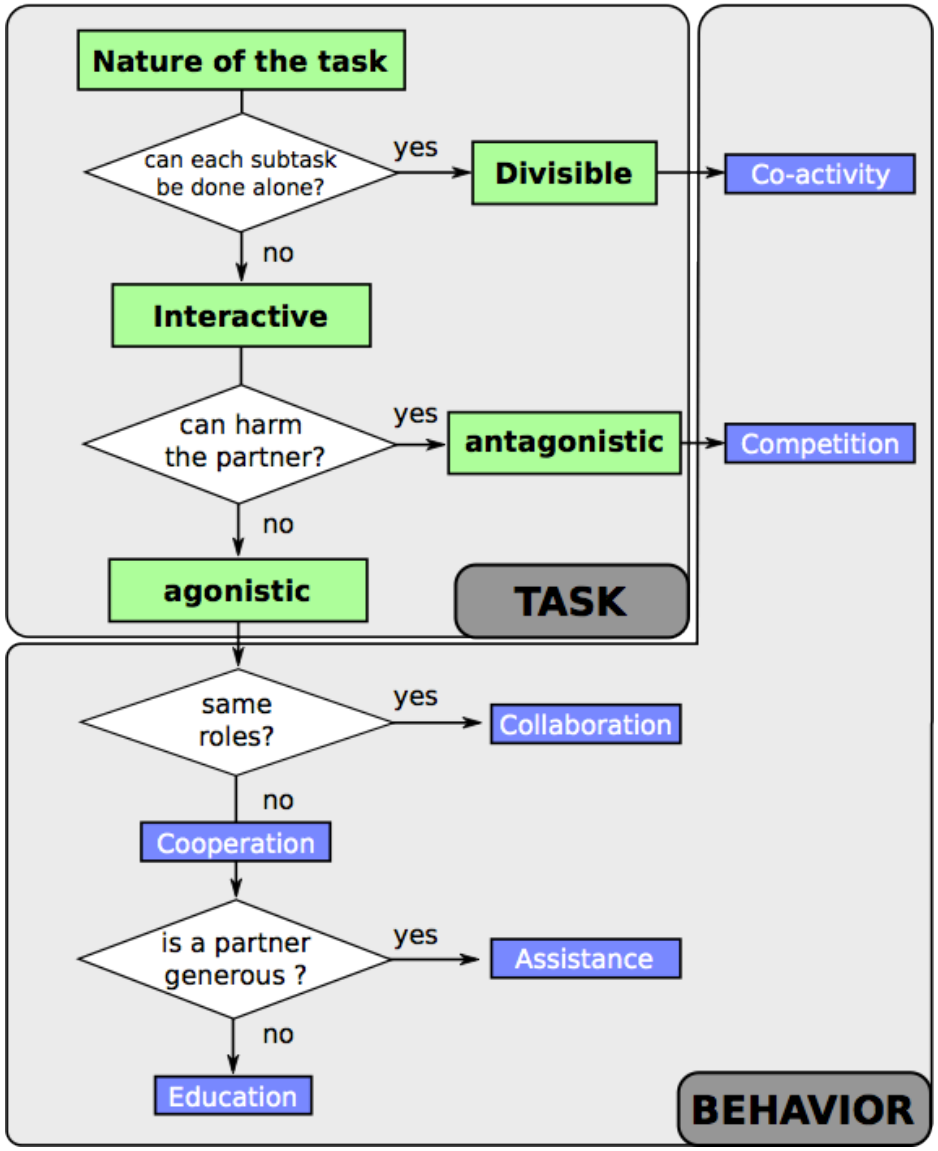
Object lifting



Wrestling

Sewing

Types of interactions



Examples:

- hybrid force/ position control, arm wrestling, autistic behaviour

- football, sumo, fighting robot

- carrying a table together, hand shaking

- teleoperation
- sport training/ coaching

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Taxonomy of interactive behaviors

Exchange	Interaction	Sub-kind	Agent 1	Agent 2
symmetric	**Collaboration**	-	$V_1(t) = \alpha_1 e_1^2(t) + \beta_1 u_1^2(t) + \gamma_1 \hat{e}_2^2(t) + \delta_1 \hat{u}_2^2(t)$ *(partner)*	$V_2(t) = \alpha_2 e_2^2(t) + \beta_2 u_2^2(t) + \gamma_2 \hat{e}_1^2(t) + \delta_2 \hat{u}_1^2(t)$ *(partner)*
	Competition	-	$V_1(t) = \alpha_1 e_1^2(t) + \beta_1 u_1^2(t) - \gamma_1 \hat{e}_2^2(t) - \delta_1 \hat{u}_2^2(t)$ *(competitor)*	$V_2(t) = \alpha_2 e_2^2(t) + \beta_2 u_2^2(t) - \gamma_2 \hat{e}_1^2(t) - \delta_2 \hat{u}_1^2(t)$ *(competitor)*
asymmetric	**Cooperation**	assistance	$V_1(t) = \alpha_1 \hat{e}_2^2(t) + \beta_1 \hat{u}_2^2(t)$ *(slave)*	$V_2(t) = \alpha_2 e_2^2(t) + \beta_2 u_2^2(t)$ *(master)*
		education	$V_1(t) = \alpha_1 \hat{e}_2^2(t) + \beta_1 u_1^2(t)$ *(teacher)*	$V_2(t) = \alpha_2 e_2^2(t) + \beta_2 u_2^2(t)$ *(student)*

- collaboration: no a priori roles distribution, roles depend on interaction history
- competition: agents focus on their own action and effort, and to this purpose can oppose the other's performance
- cooperation: different roles are ascribed to the agents prior to the beginning of a task

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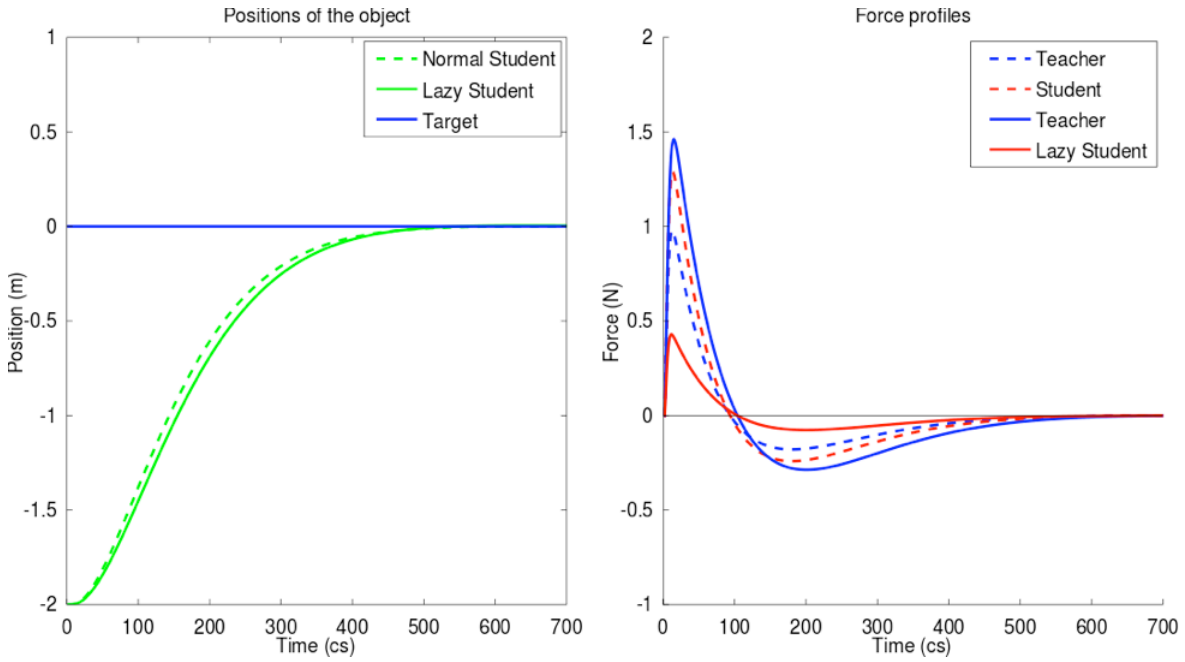
Simulated interactions

- Taxonomy can be used to generate dyad motor interaction behaviours, e.g. move an object together
- simulating the interaction of two (point-mass) human arms



Education: movement is faster with the hardworking student and the teacher can reduce his relative effort

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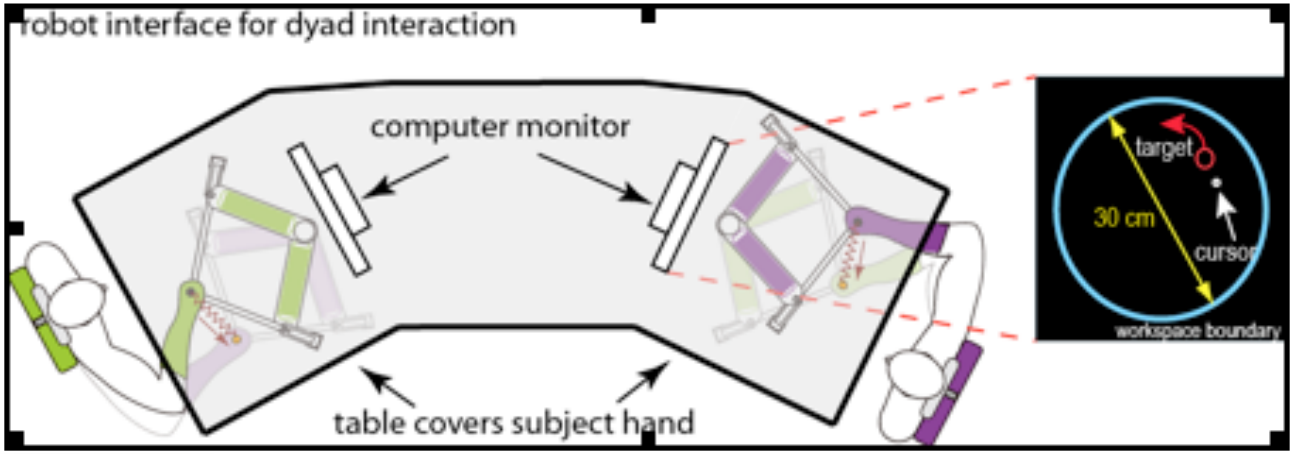
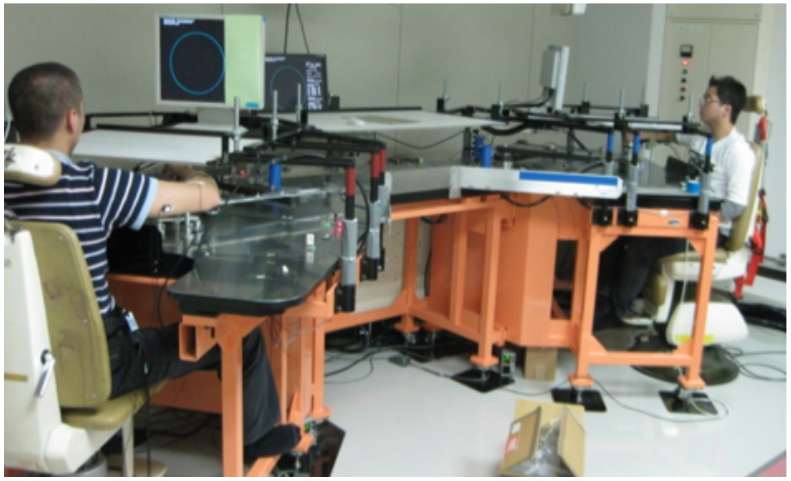
Benefits of interaction

- how does haptic interaction influence individual motor behaviors?
- can one agent utilize information about the other's behavior to improve its behavior?
- what is the computational process of the interaction?

Experiment





- task: track a randomly moving target
- the subjects get same target trajectory and their respective hand position, and can work independently
- they do not know that/when they are connected

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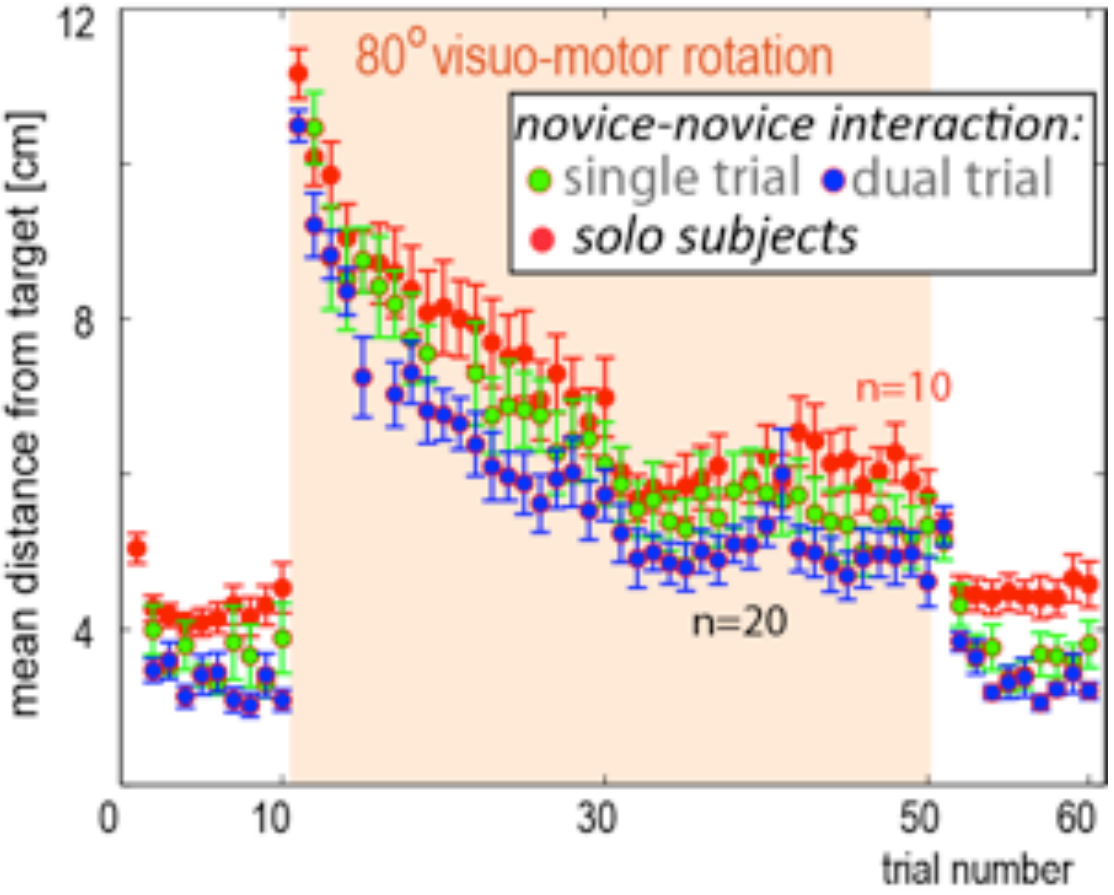
Effects of interaction



how to explain these results?

- connection improves tracking performance
- single performance better than solo subjects!

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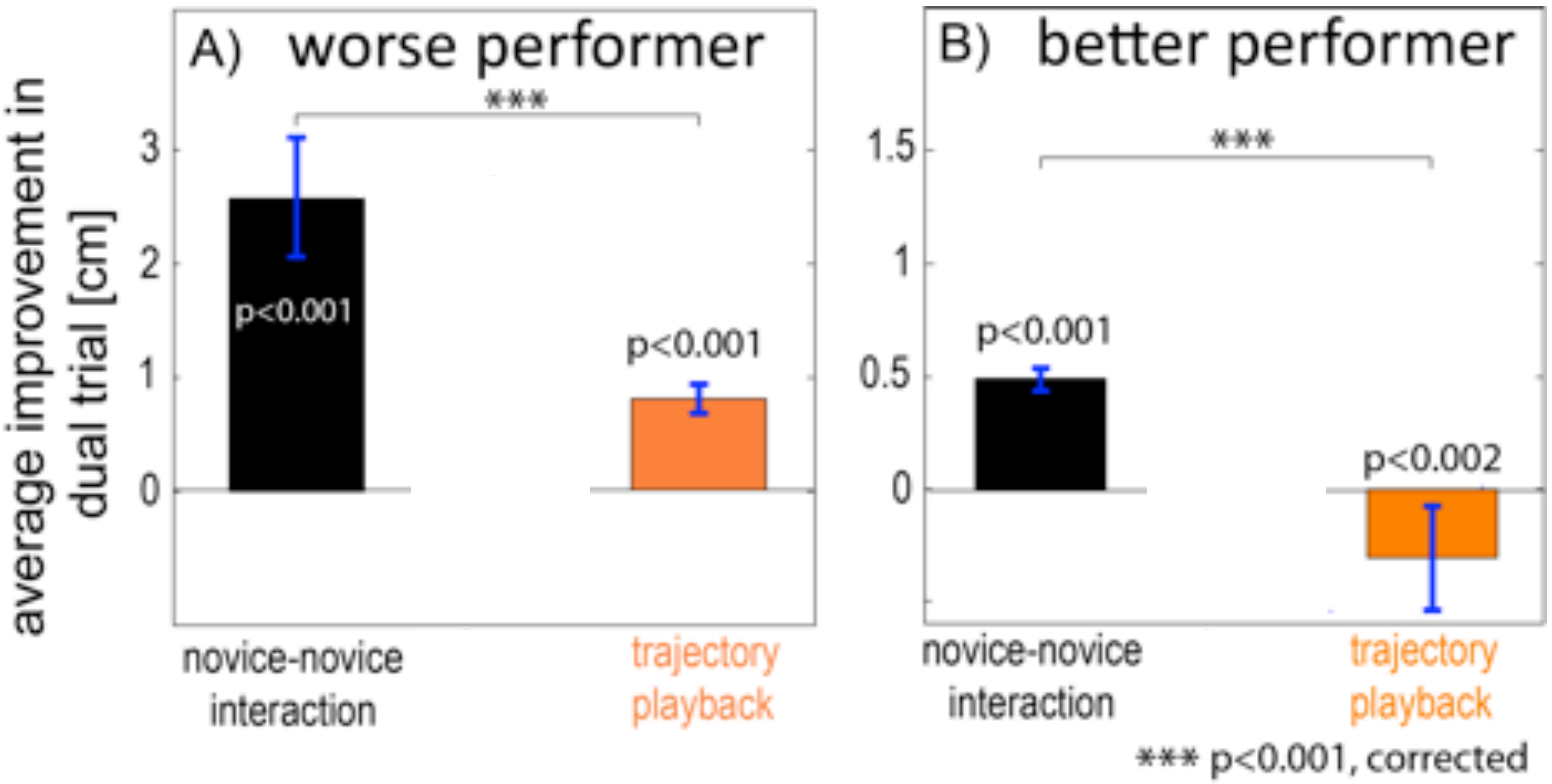
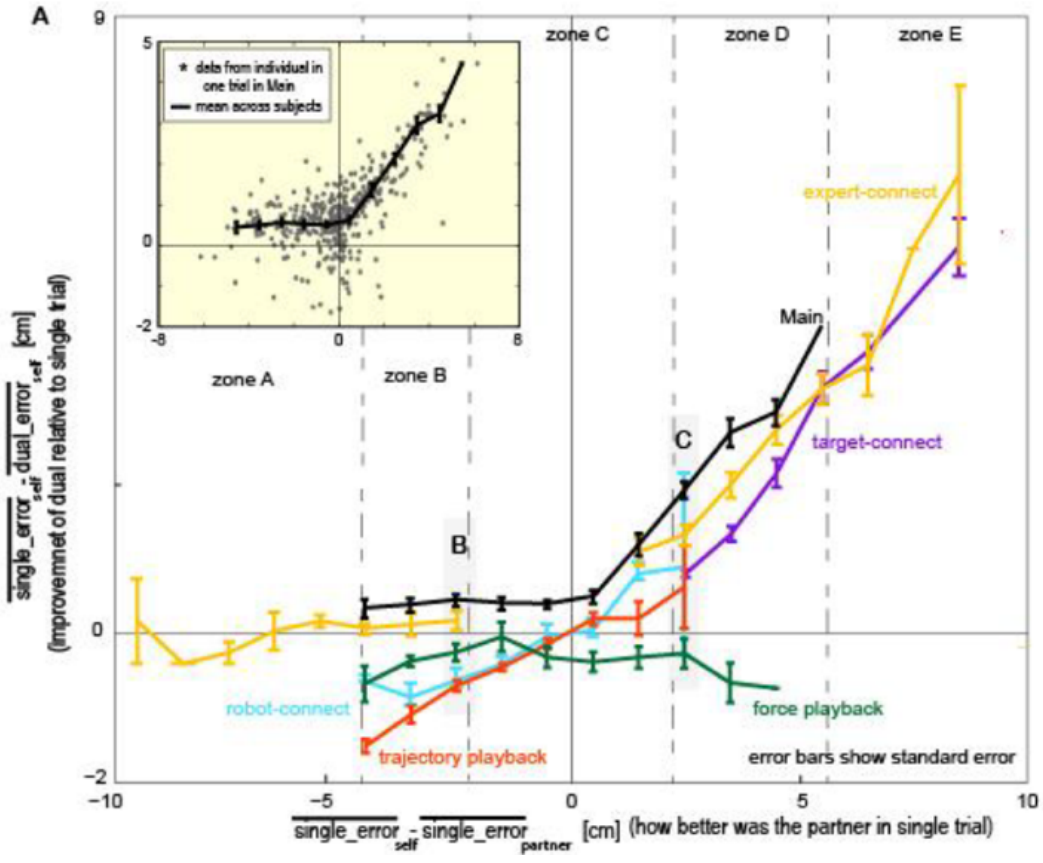
Analysis of interaction benefit



- one-way connection: improve only with better partner
- two way connection: improvement in worse and best partners!

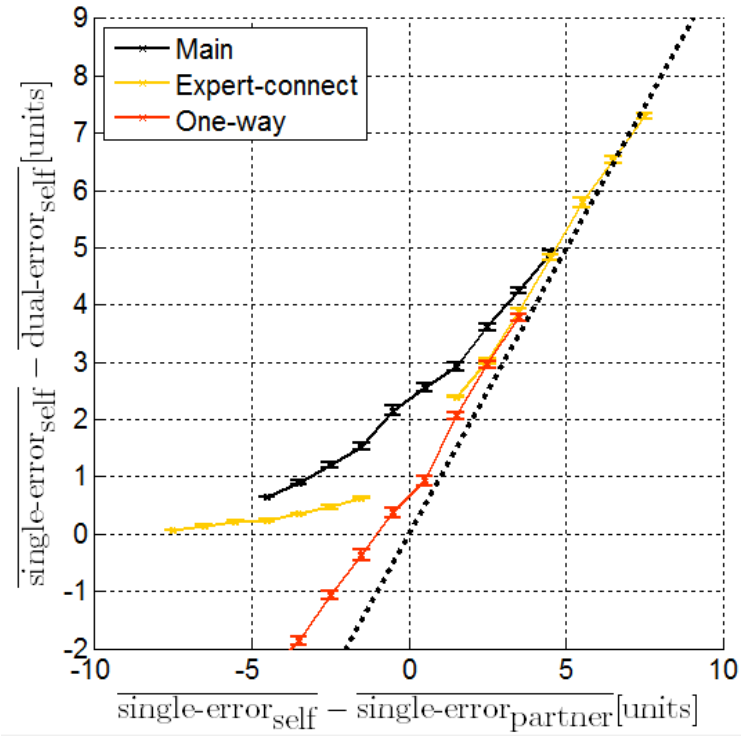
-> stochastically optimal combination of own and partner signals?

Optimal estimation from own and partner feedback signals



data

simulation



- Humans combine information from interacting partners in a optimal way
- **This suggests new modalities for interactive training with robots**

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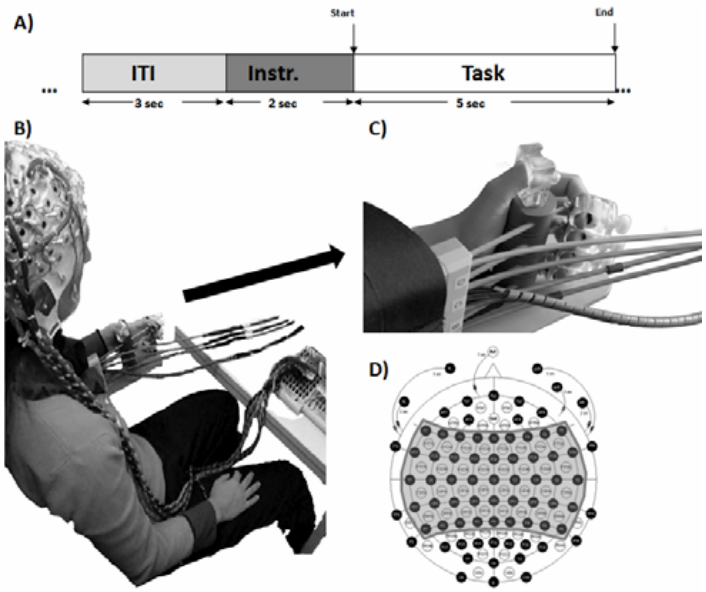
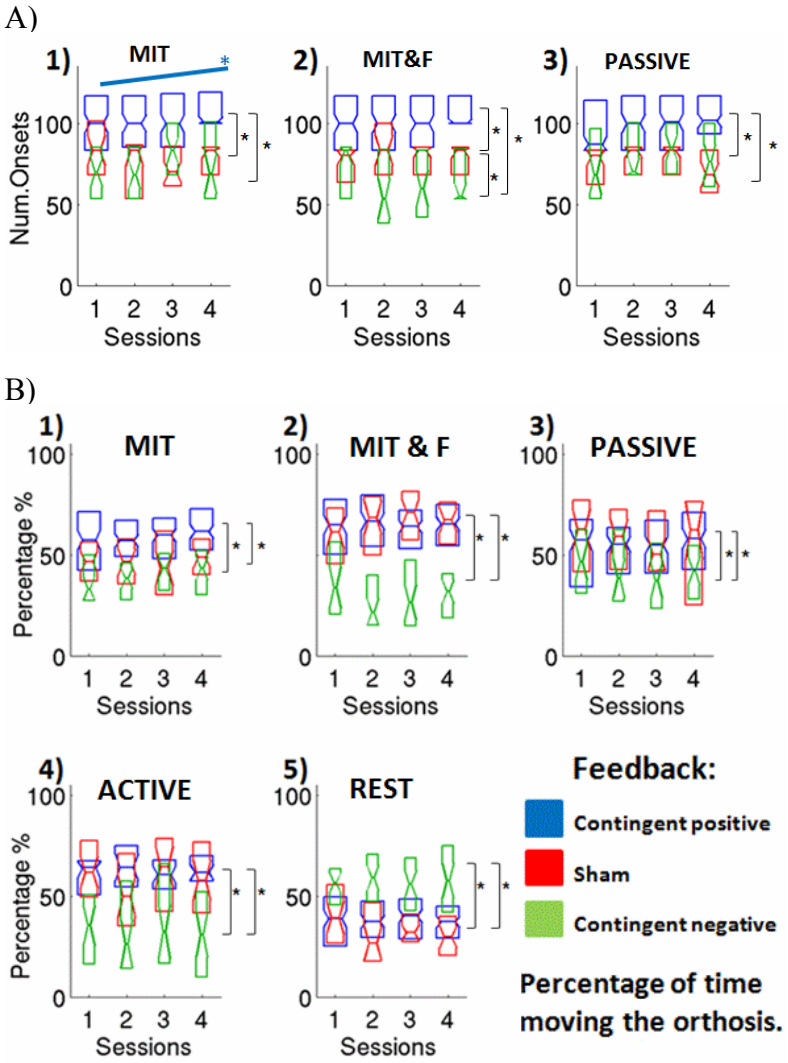
A general theory for human-like interactive behavior

- Physical **collaboration** between humans **improves** individual's performance and learning
- In human-human cooperation, **different roles** may emerge for the individual subjects
- In haptic interaction among humans, the **amount of information** on partner's actions affects the other partner's coordination

Towards a haptic BCI for motor rehabilitation

- Afferent feedback due to haptic interaction with robot orthosis
- How does it affect BCI-based control?
- How does it affect learning of control?

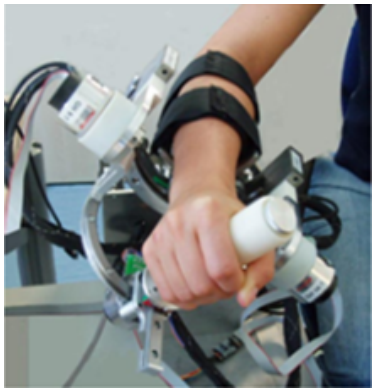


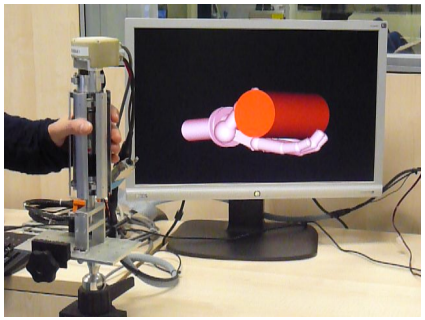


Ramos-Murguialday A., Hammer E. M., Caggiano V., Schürholz M., Halder S., and Birbaumer N. (in preparation) On-Line haptic BCI.

Technological contributions

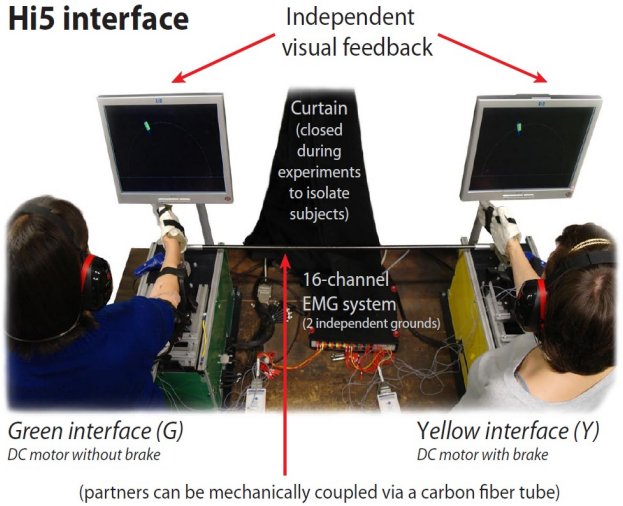
- Wrist Unit
- Grasp Unit





- Impedance device

- Dual wrist (Hi5) device



Advanced approaches to robot-assisted neuro-rehabilitation

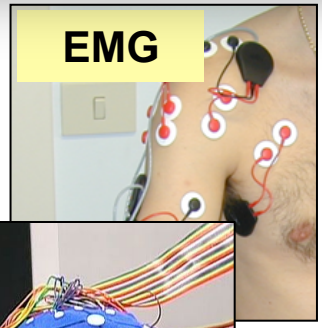
1. Can we identify the **recovery mechanisms** of our patients during training?
2. Can we exploit these mechanisms to **optimize and adapt training** based on patients performance?
3. Can we maximize patient **motivation** and promote **generalisation** processes through varied therapy practice using a performance-based regulation of training?
4. How to **regulate assistance** to maximize recovery in tasks that involve multiple sub-movements?
5. How the **different characteristics** of our patients influence the motor recovery?

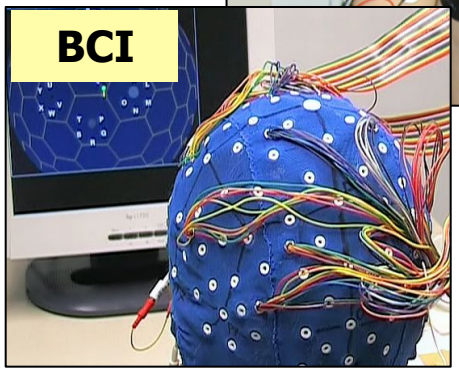
impact on clinical practice

High ← Patient Impairment → Low

- Time - Triggered Assistance
- Assist-as-needed
- Activity - Triggered Assistance
- Negative Assistance

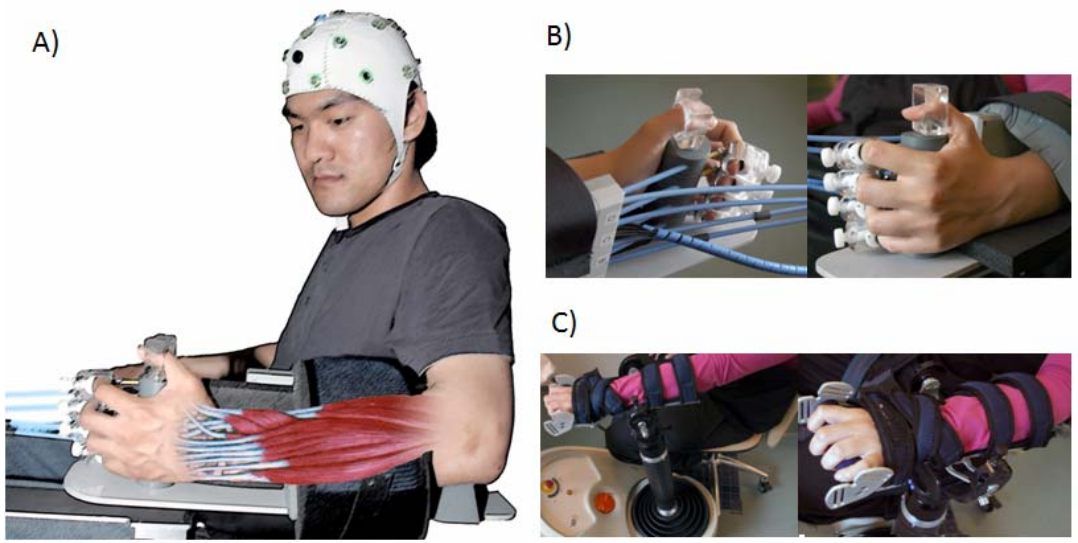
Easy → Task difficulty Level → Difficult



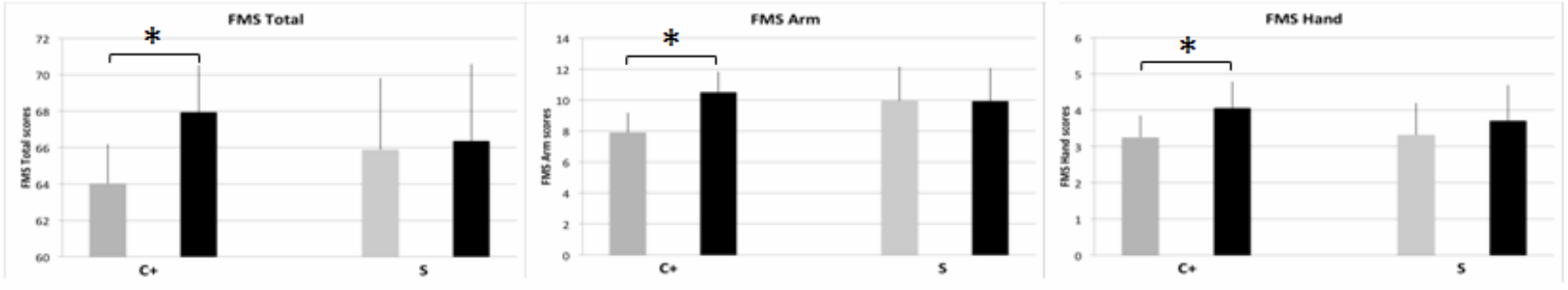


An integrated set of tools to promote/maximize recovery

Haptic BCI to promote stroke recovery

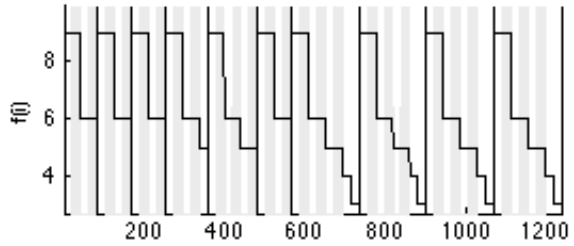


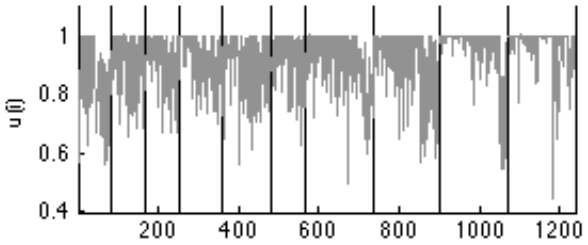
- Haptic BCI training elicits clinically significant recovery of arm and hand functions

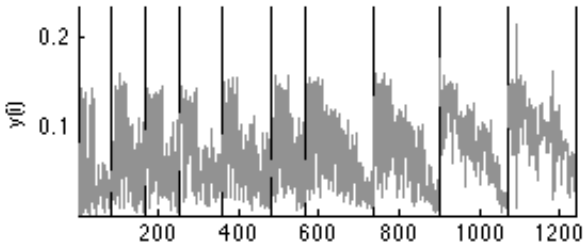


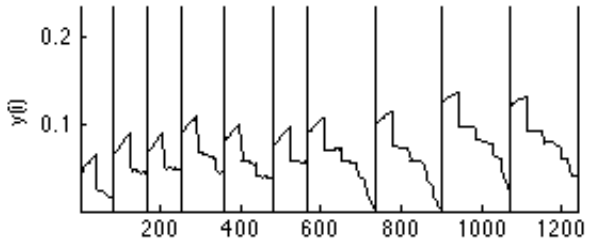
Ramos A et al (in preparation) Efficacy of combined brain-computer interface (BCI) and physiotherapy in chronic stroke: a controlled double-blind study

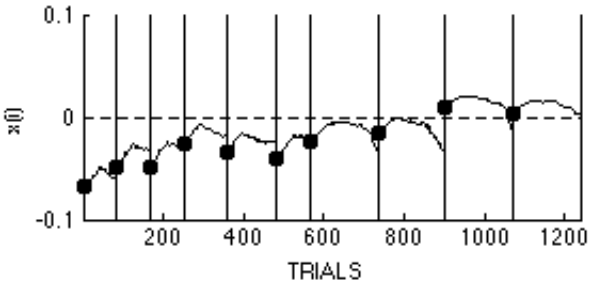
A model of neuromotor recovery after stroke

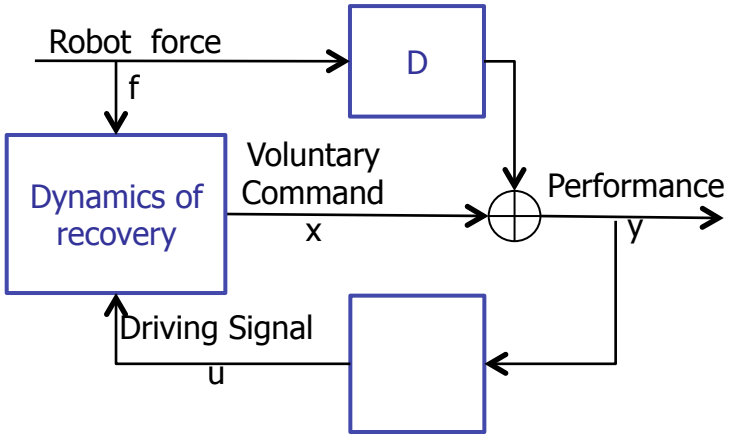


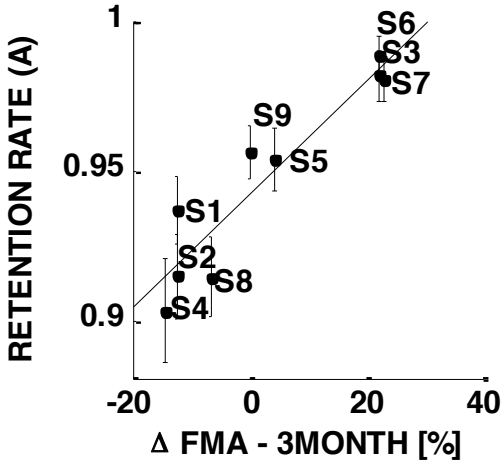




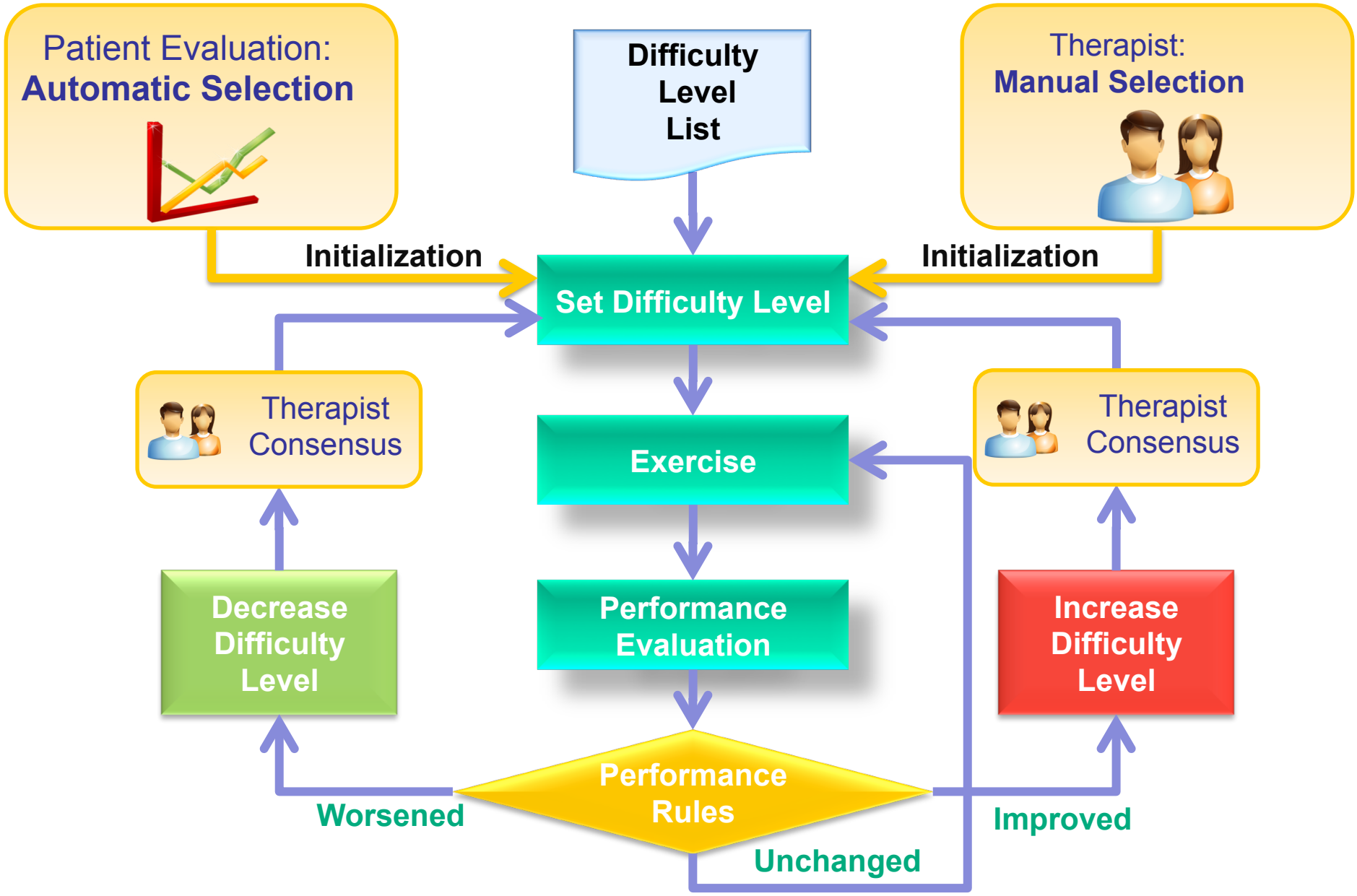








Casadio M, Sanguineti V (in press) Learning, retention and slacking: a model of the dynamics of recovery in robot therapy. IEEE Trans Neural Systems Rehab Eng



R. Colombo et al (in press) Taking a lesson from patients' recovery strategies to optimize training during robot-aided rehabilitation. IEEE Trans Neural Sys Rehab Eng

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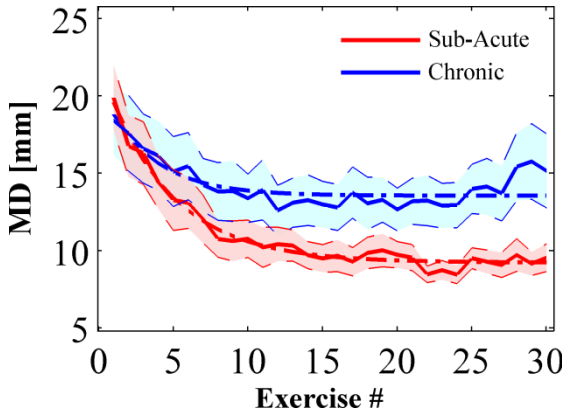
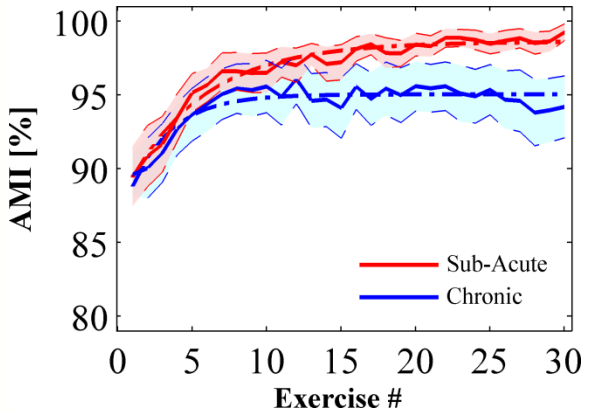
I.R.C.C.S.

humour

Continuous Regulation of Assistance (Bayesian Algorithm)





(SA:17, C: 18)

- Clinical project outcomes are currently used in the treatment of subacute and chronic stroke survivors at Fondazione Maugeri, Veruno (IT)

The humour consortium

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- **D. Popovic**, M. Popovic, S. Dosen, M. Kostic
- **R. Colombo**, F. Pisano, C. Delconte, I. Sterpi, A. Mazzone
- **N. Birbaumer**, A. Caria, A. Ramos, M. Schurholz
- **H. Heuer**, K. Rapp, J. Luttgen
- **E. Burdet**, A. Melendez, S. Balasubramanian, R. Secoli, V. Komisar