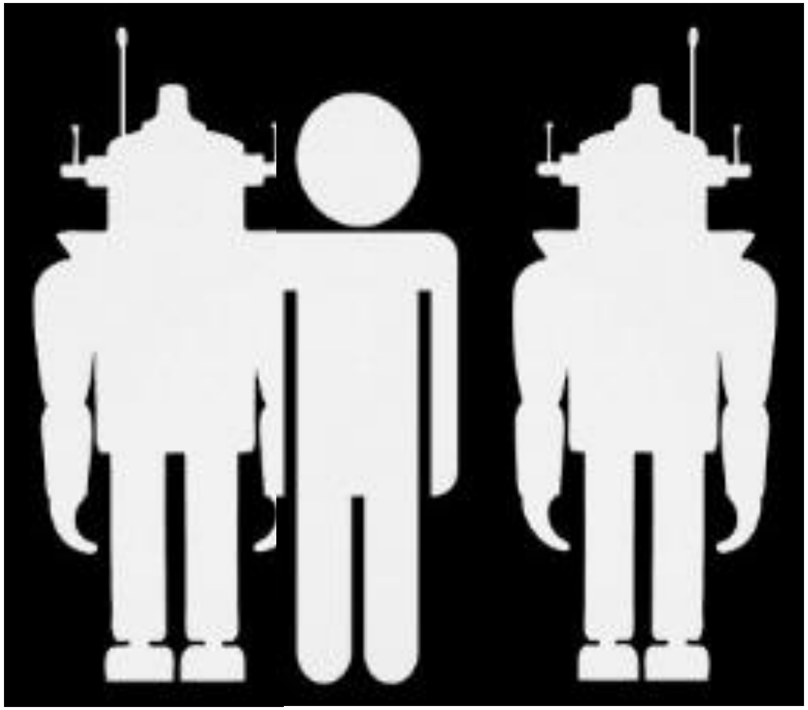
Human Centric Robotics



Understanding the neuroscience, and control underlying physical interactions by human for the development of next generation medical and social equipment and robots

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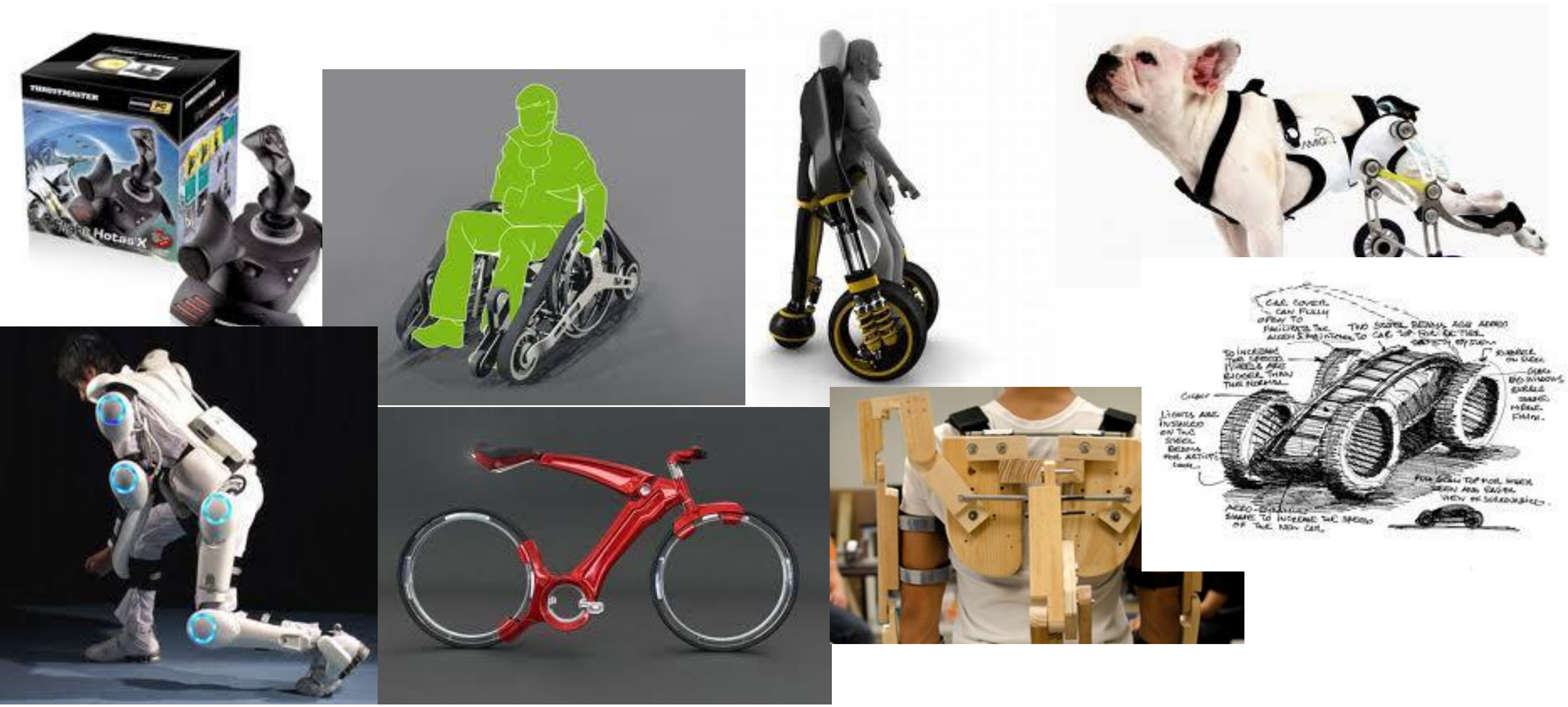
Machine design for man



machine design is defined by human biomechanics and aesthetics. However, designs sometimes require to consider 'human movement control' and human behavior.

Designing for control: golf driver (wood)

light, flexible shaft helps store and release energy

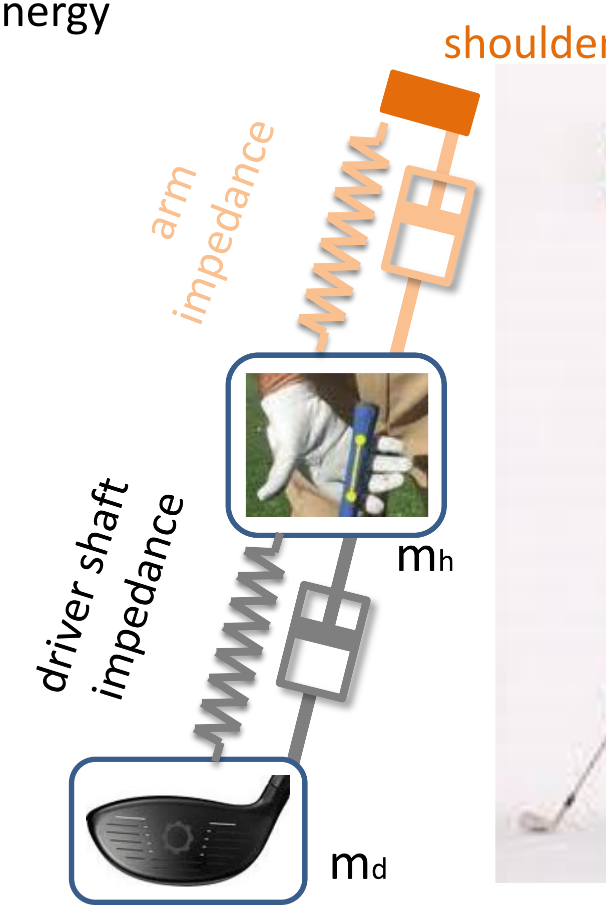
shaft impedance is key!

Current shaft impedance optimized to individuals height, style and driver head size

but arm impedance is neglected

Arm impedance determined by--

- posture and online arm muscle activations and dynamic
- Human impedance control and adaptation- humans implicitly adapt their posture/muscle activations depending on the tool and task



Developing (powered) smart golf drivers with impedance control

Funded by JST (Japan), DFG (Germany)

Designing for control: golf driver (wood)

Humans have ability to optimize impact impedance - the 'when' and 'how' of this process is little understanding

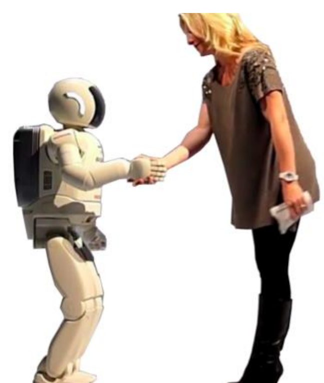
understand human *impedance control dynamics* to optimize design of sports equipment for impact tasks

Developing (powered) smart golf drivers with impedance control
Funded by JST (Japan), DFG (Germany)

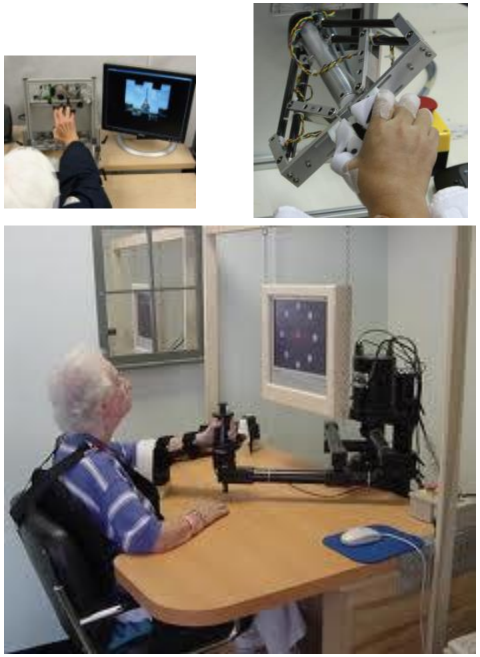
Machine design for man

Design of machines interacting with humans can be improved by understanding human movement control

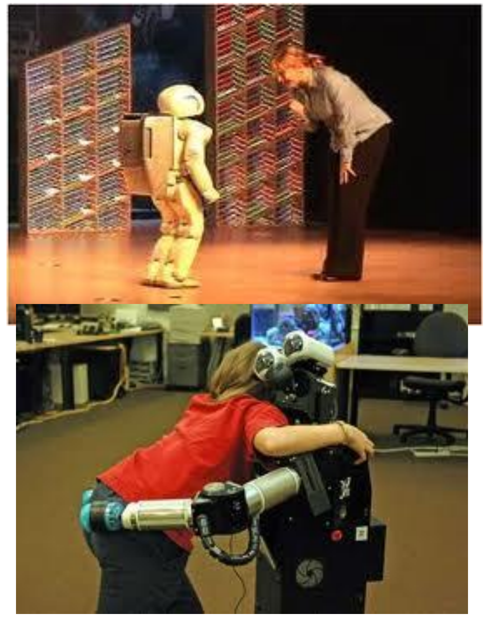
Human-robot interactions are more challenging



Robots are active interacting agents



Rehabilitation



Social robotics

Medical robotics

- How should robots look/behave such that humans feel comfortable, safe with them?
- benefit physically and psychologically from them?

Complex human interaction dynamics

Humans interactions change with

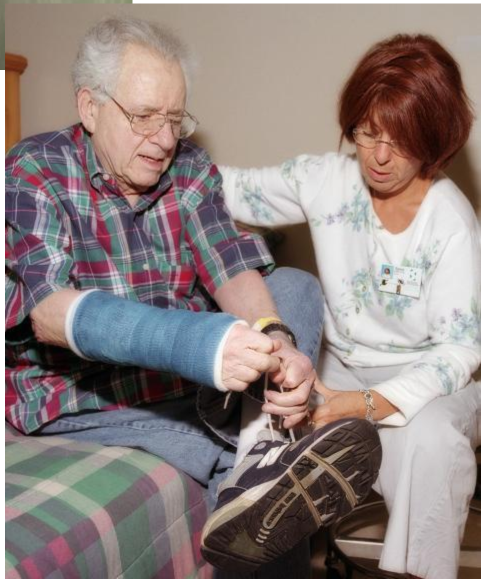
- Body dynamics, control
  (golf driver example)
- Age
- Disease

- Cognitive factors
  - Anxiety
  - Fear
  - Mood

- Theory of mind
  - What one expects of his partner?
  - What interacting partner expects of him?

Humans- the ideal partner

Humans consider all these factors when interacting with each other and with their environment

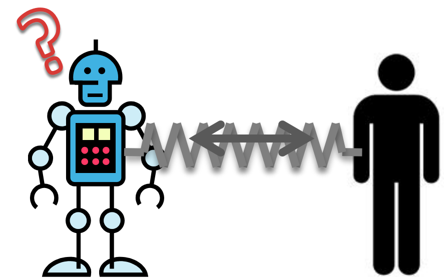


Future robots need to do the same!

How to control human-robot interactions?

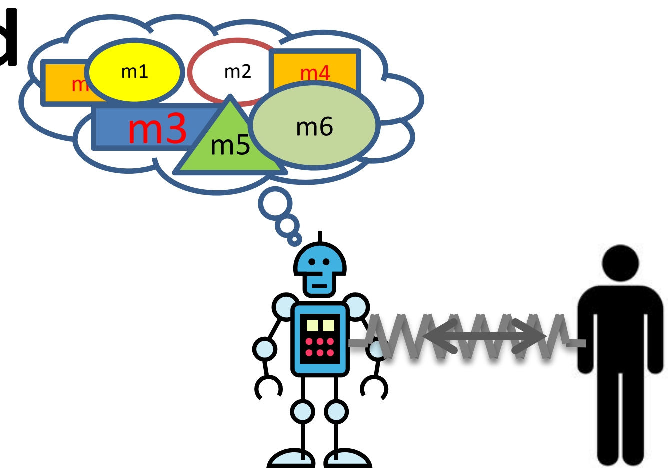
- **Solve human black box during interaction**

but humans are too complex!



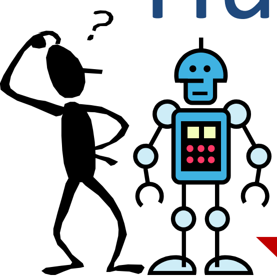
- **Interact utilizing predefined models of human behavior**

but we need the models first.



We require human centric robot control!

Human centric Design and robotics



Human- motor interactions

- How humans utilize various visual and haptic

- How interactions with other humans affects one's own behavior?
- How human behaviors change with time, age, disease ?

Machine-Human interactions

- How control and mechanical dynamics

- How the design/ aesthetics of robots be improved?
- What robot behavior will help humans adapt faster, feel safe?

Cognitive factors during interaction

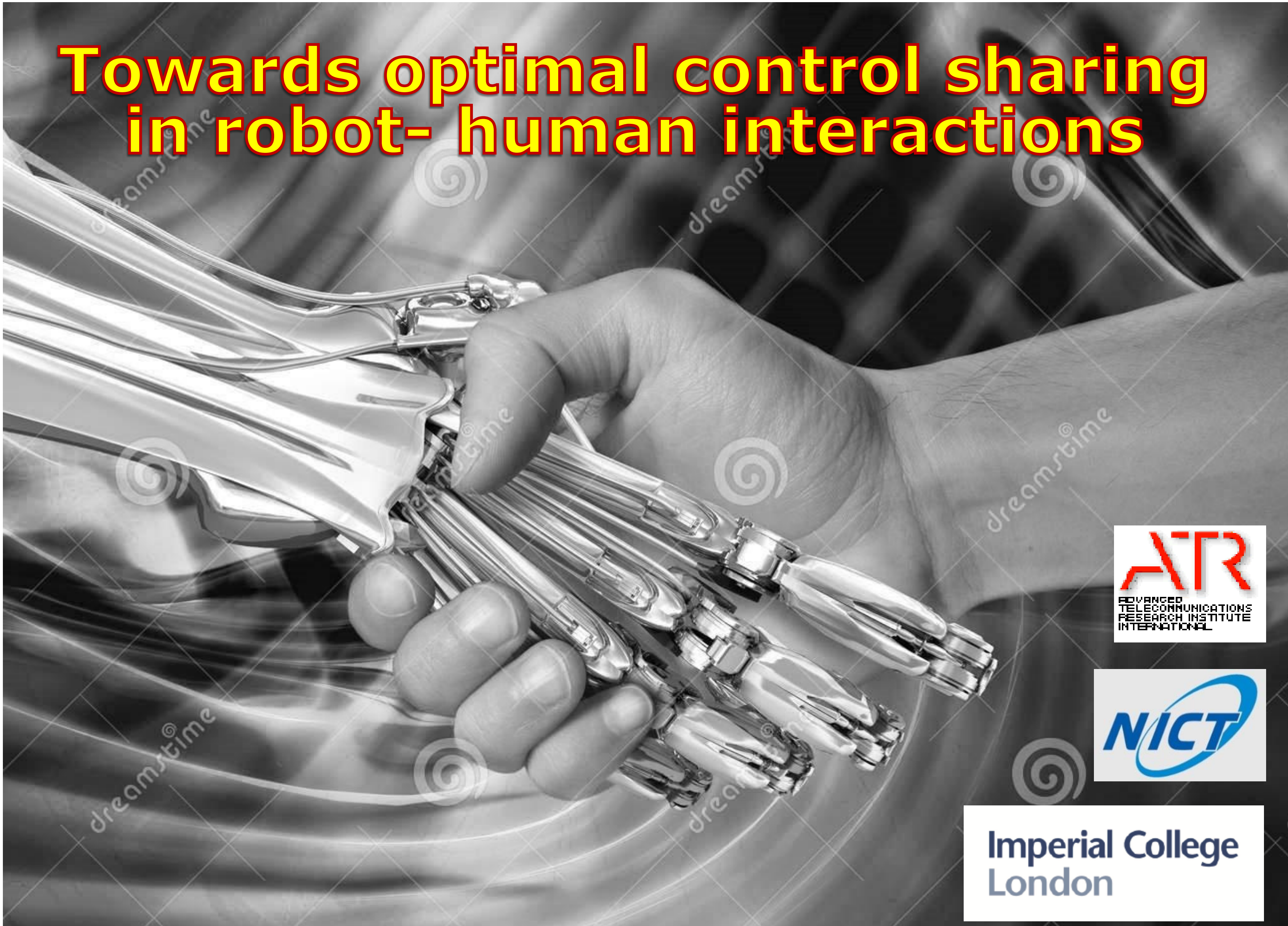
- How the explicit mechanisms (Theory of

anxiety and competition affect motor control /learning.

- How these can be used for a benefit of robotics?

Requires research in robotic design, control and human motor Neuroscience

Towards optimal control sharing in robot- human interactions



Robot-human control sharing

balance control

$= F(\alpha \text{ robot}, \beta \text{ human})$

$\alpha, \beta = ?$

Walking, balancing in a exoskeleton

Re-learning to walk with a rehab-robot

- least interference
- compensate for each others mistakes
- easy for human, robot to adjust to each other
- promote learning between robot-human

Human –human interactions

Explicit and discrete audio, visual and haptic




Continuous physical

Explicit interactions : researched under Social Neuroscience and Theory of Mind and applied in social robotics

Physical interactions

- fundamentally different – implicit, involves multi-body dynamics
- Research lacking, neural mechanisms still largely unclear

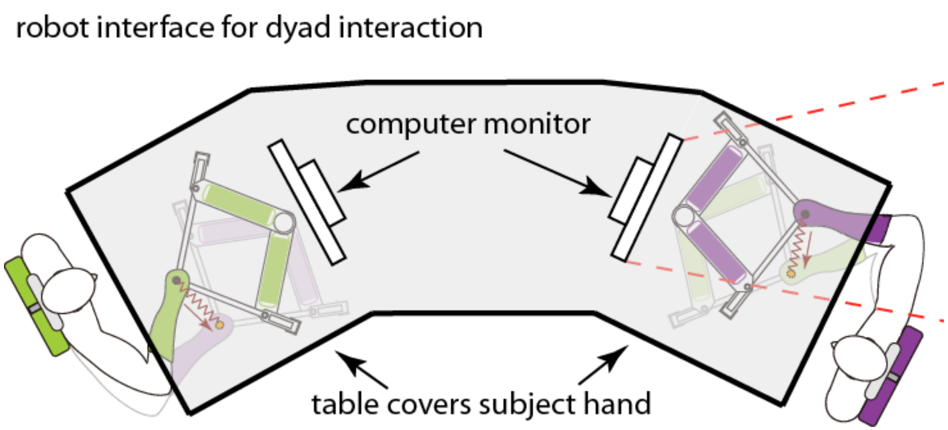
Neuroscience Questions




- Does TOM act at low level of motor control? Such that we have can models/ expectations during physical interactions?
- Does our CNS recognize an interacting agent to be human? Does it influence its behavior?
- What are the neural mechanisms underlying physical interactions?

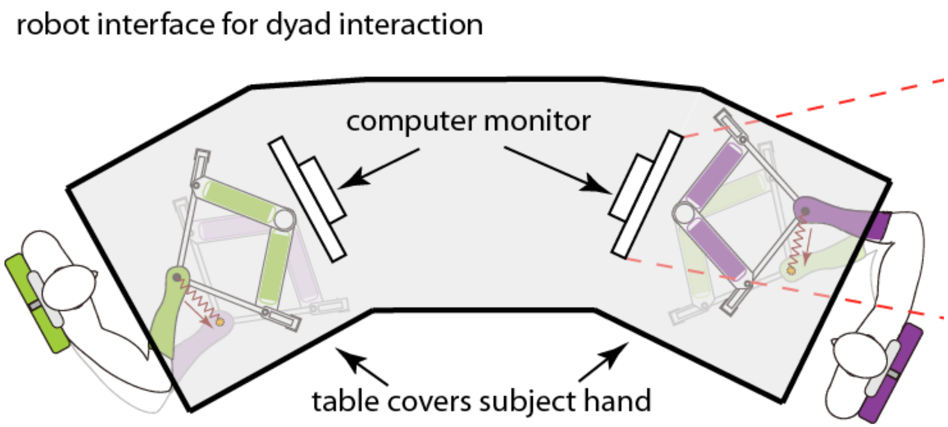
Interactive motor task design

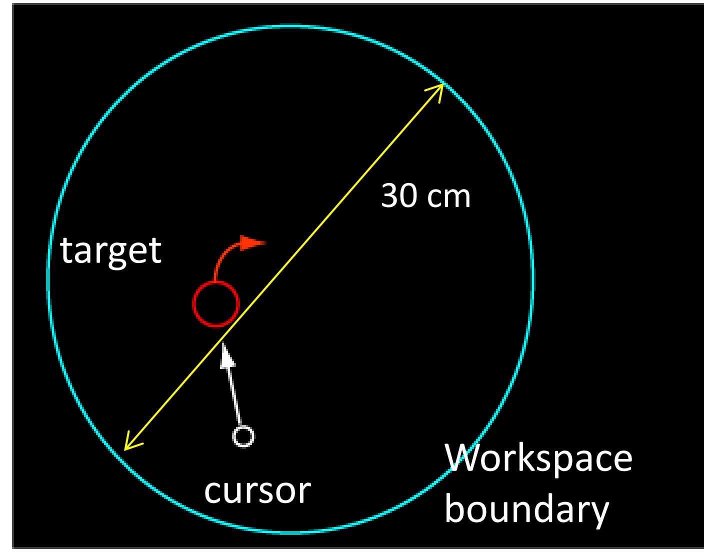
- Relatively simple yet rich
- Enables easy control and modifications of the interaction characteristics
- Enables recording of human movements

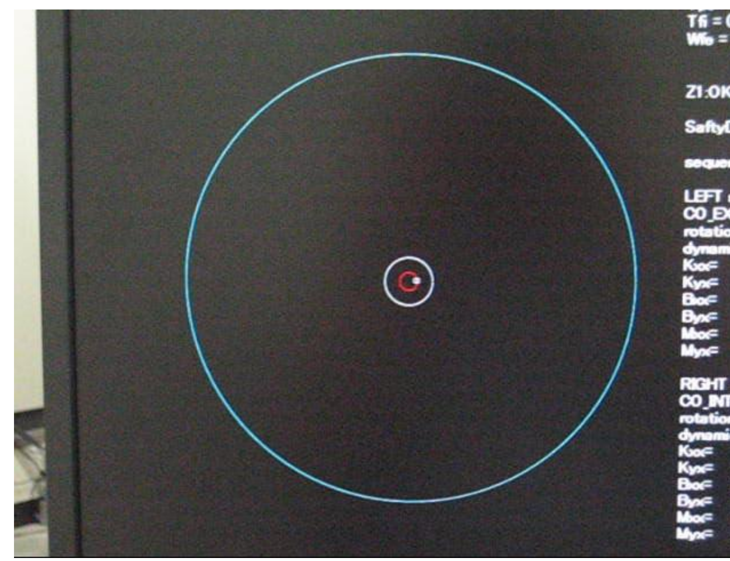


- 2 robot system that subjects can hold and manipulate
- Visual feedback of cursor position
- Interaction forces generated by robots

Interactive Motor task design







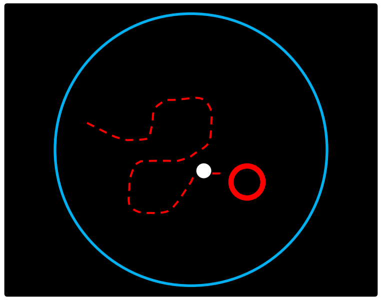
- Task: tracking a randomly moving target
- 80 subjects in total

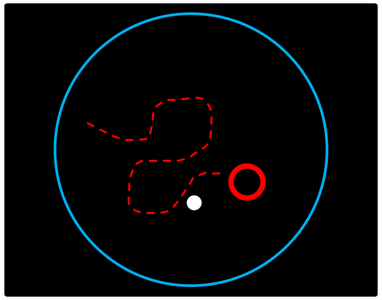
- Series of (1 min) trials; two random types

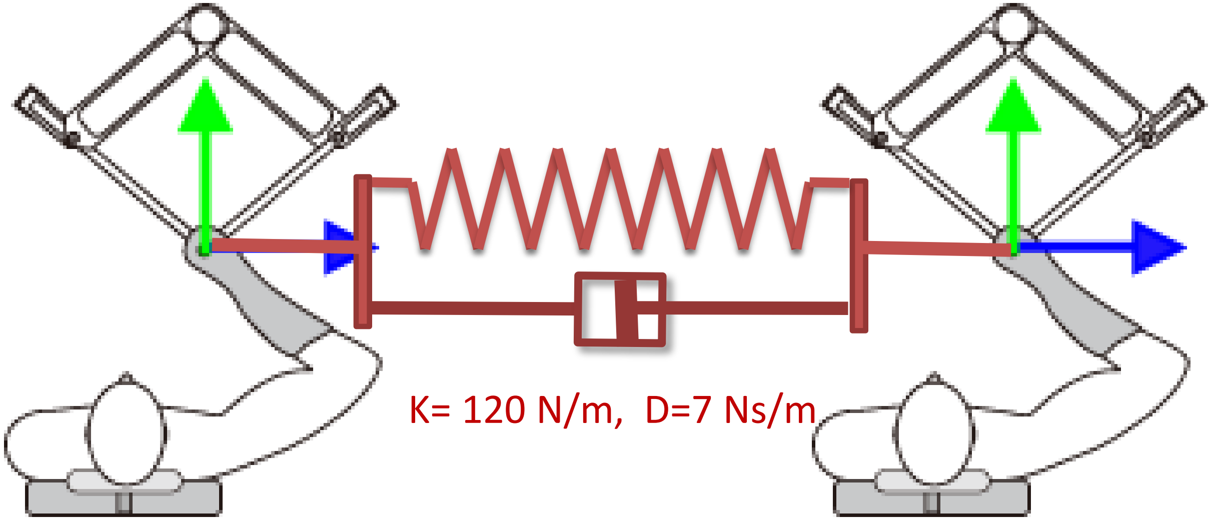
SDSDSSDDSDSSDSDSDDSD….

***single trial* (S)** and ***dual connection trial* (D)**

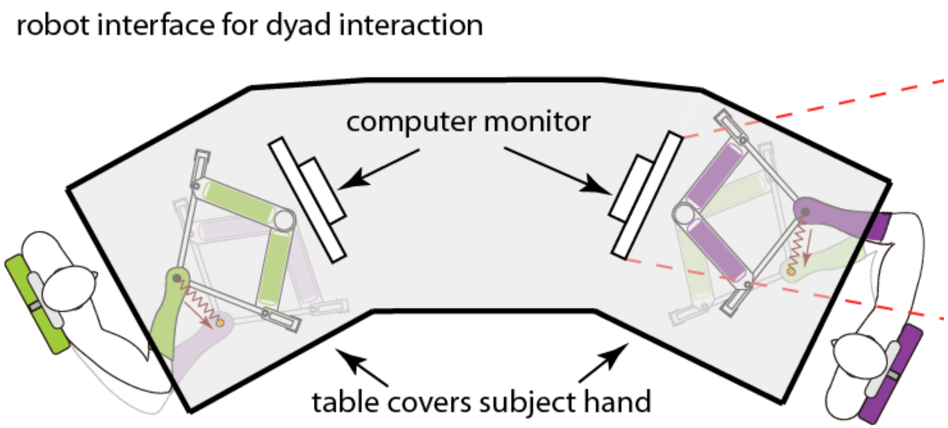
Single and Dual trials

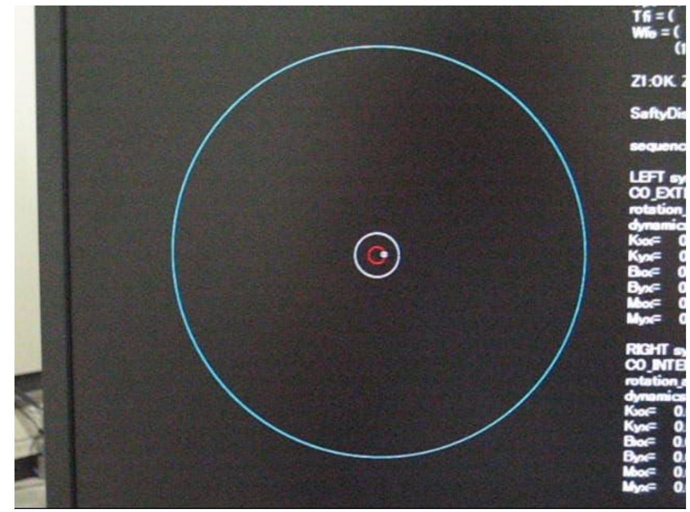






Benefit of interaction



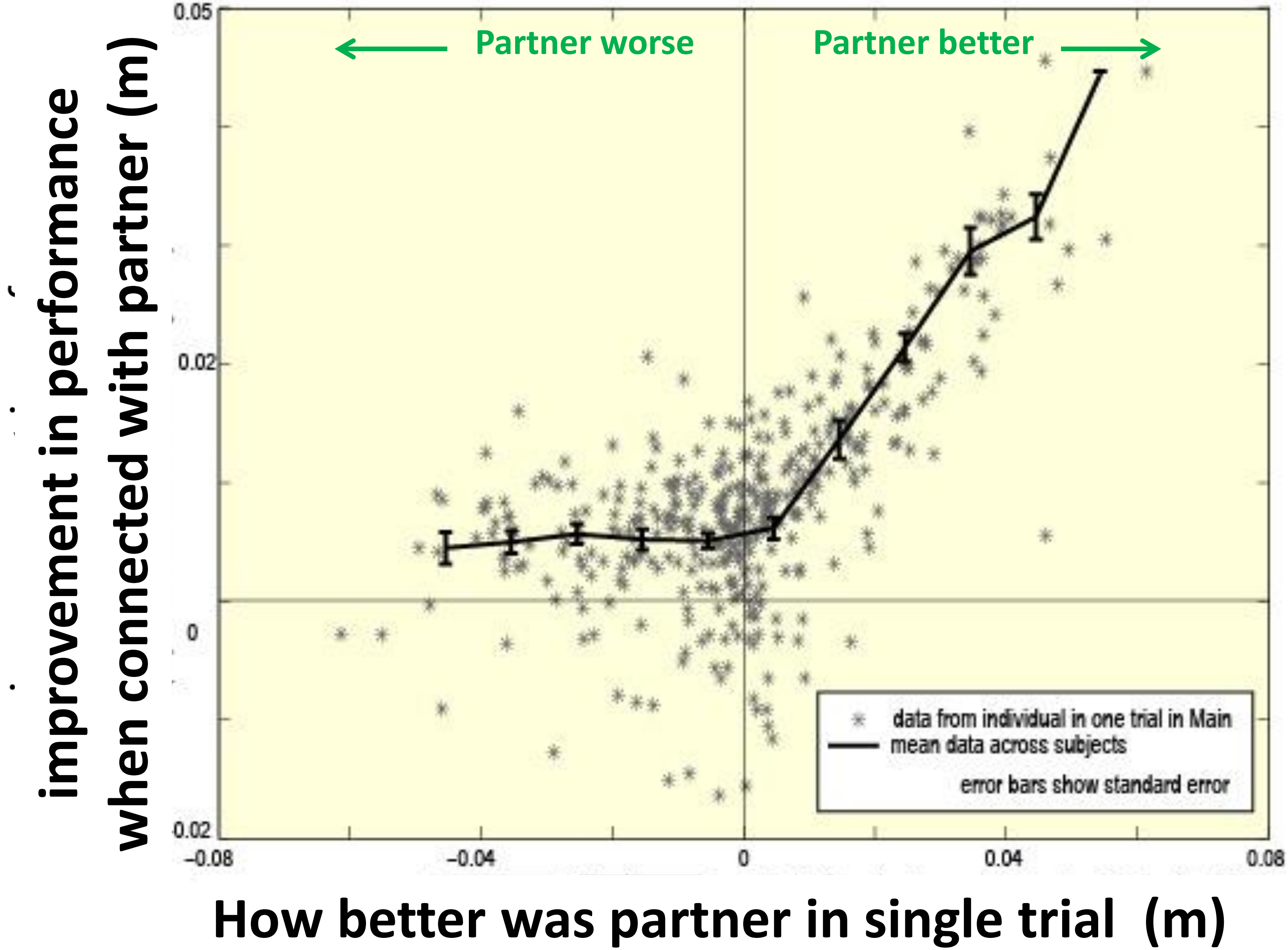


SDSDSSDDSDSSDSDSDDSD....

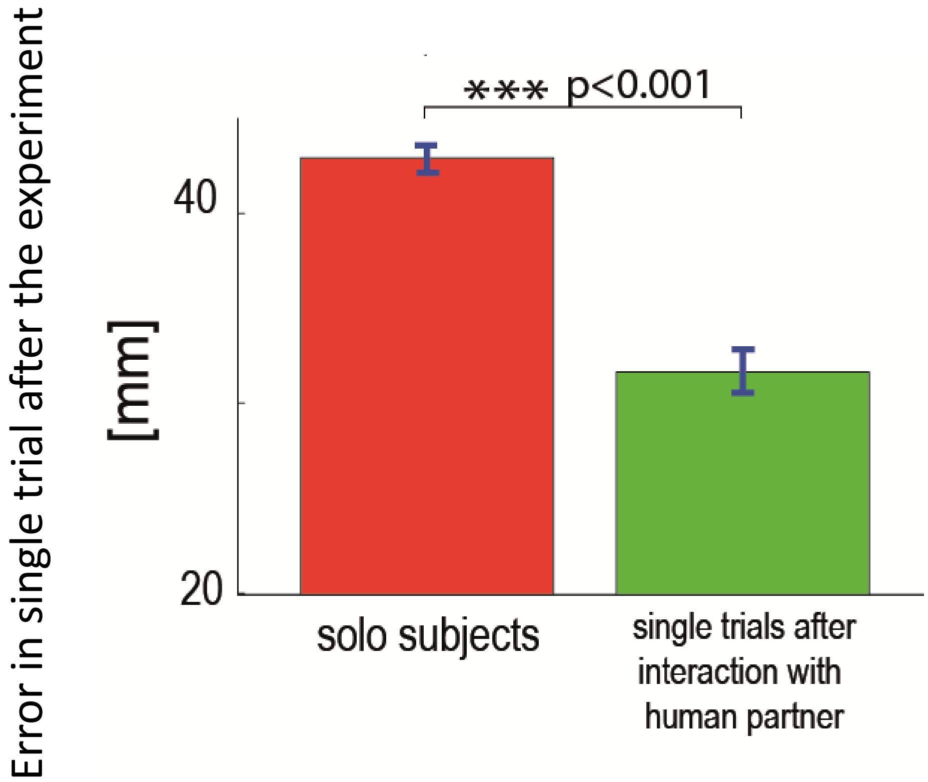
how the performance of each individual (better and worse performer) is affected during interaction?

$$(D_{performance} - S_{performance})$$

Benefit of interaction

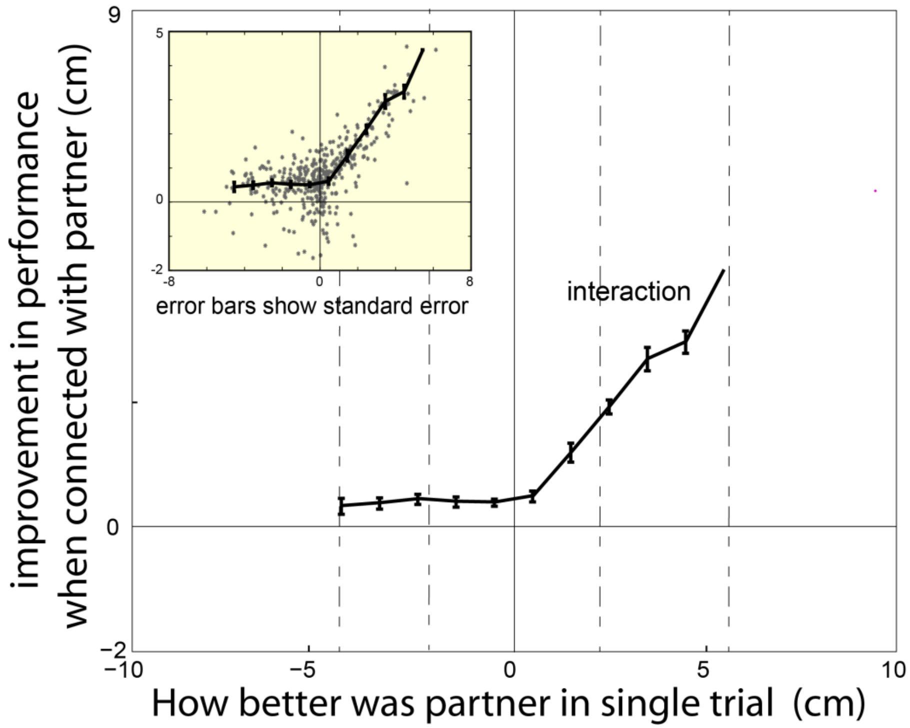


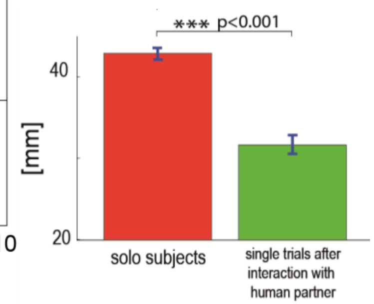
Learning: subjects skill improves by interaction

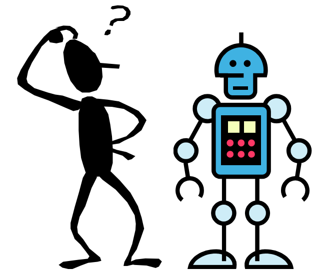


Solo subject: train for the same time but never get connected to a partner

Benefit of interaction

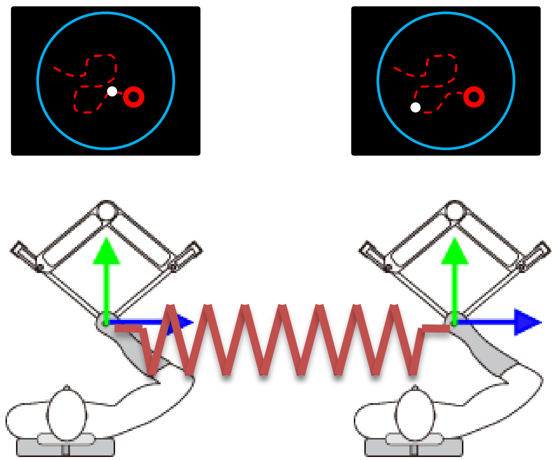


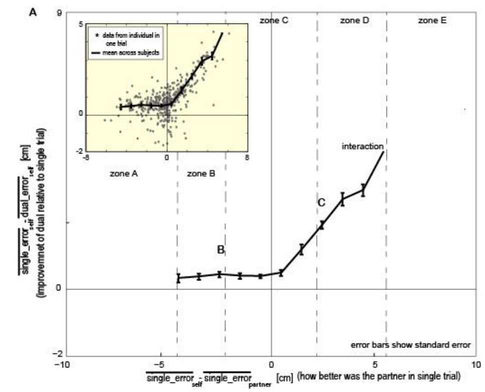




What should robots do to enable mutual benefits in robot-human interactions?

How interaction benefits both partners?

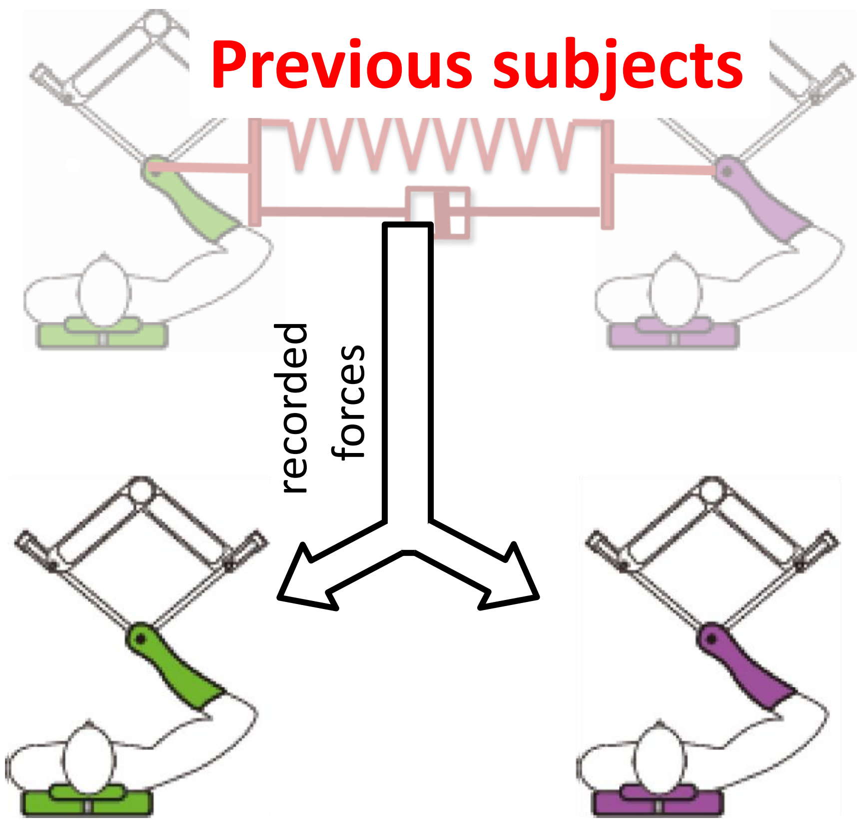




1. Is the presence of ‘any’ interaction forces the key?
   - Increased attention in connected trials
   - Increased general arm impedance hence system dynamics
   - ‘Follow the better’ strategy: eg. subject relaxes when external disturbance helps task and fights against it if it disturbs task.

•Control experiment1- with recorded connection forces

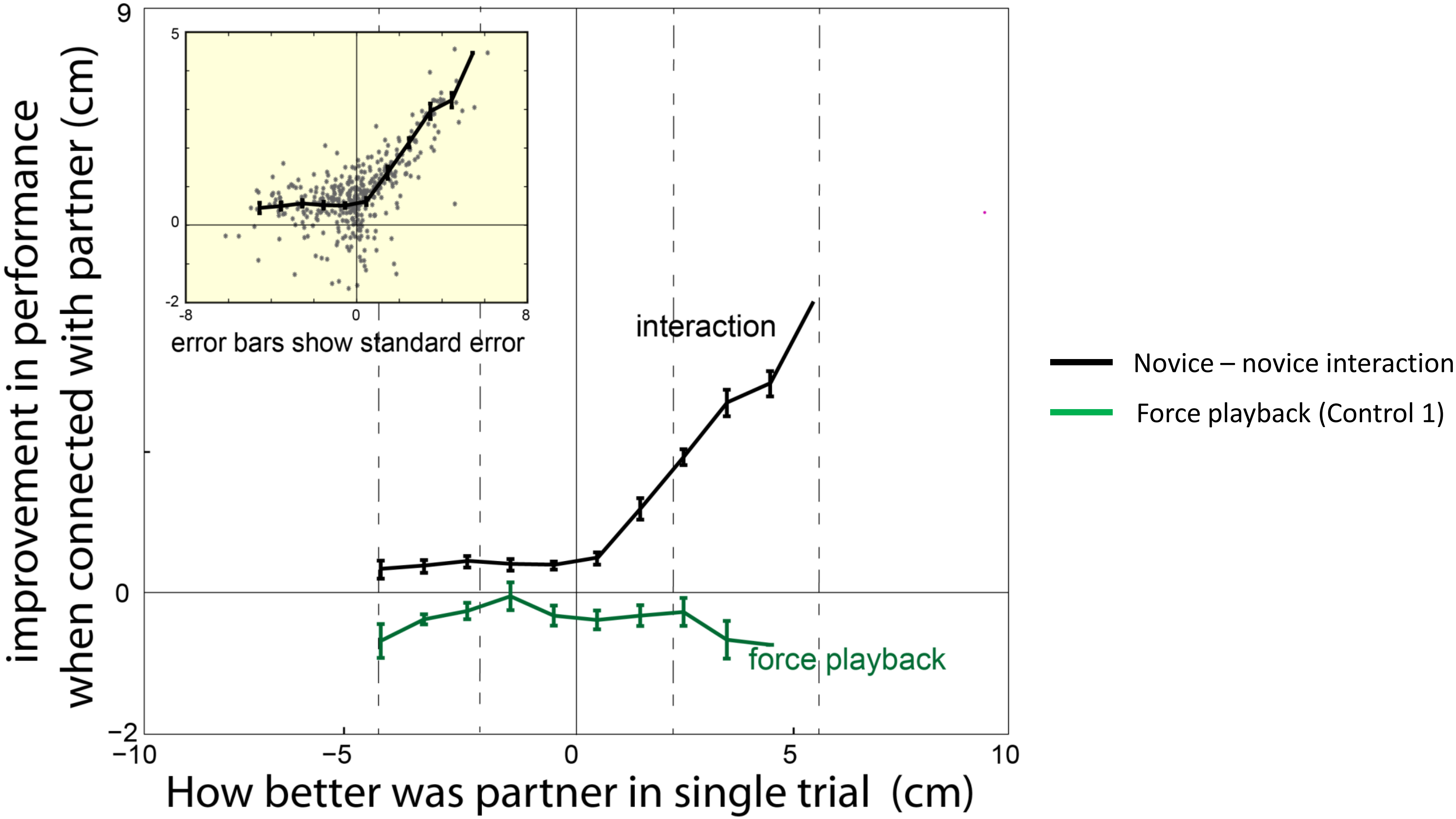
Control1: force playback



new set of subjects SDSDSSDDSDSSD…

- magnitude, frequency of forces replicated
- target velocity, position dependencies replicated

Control1: force playback

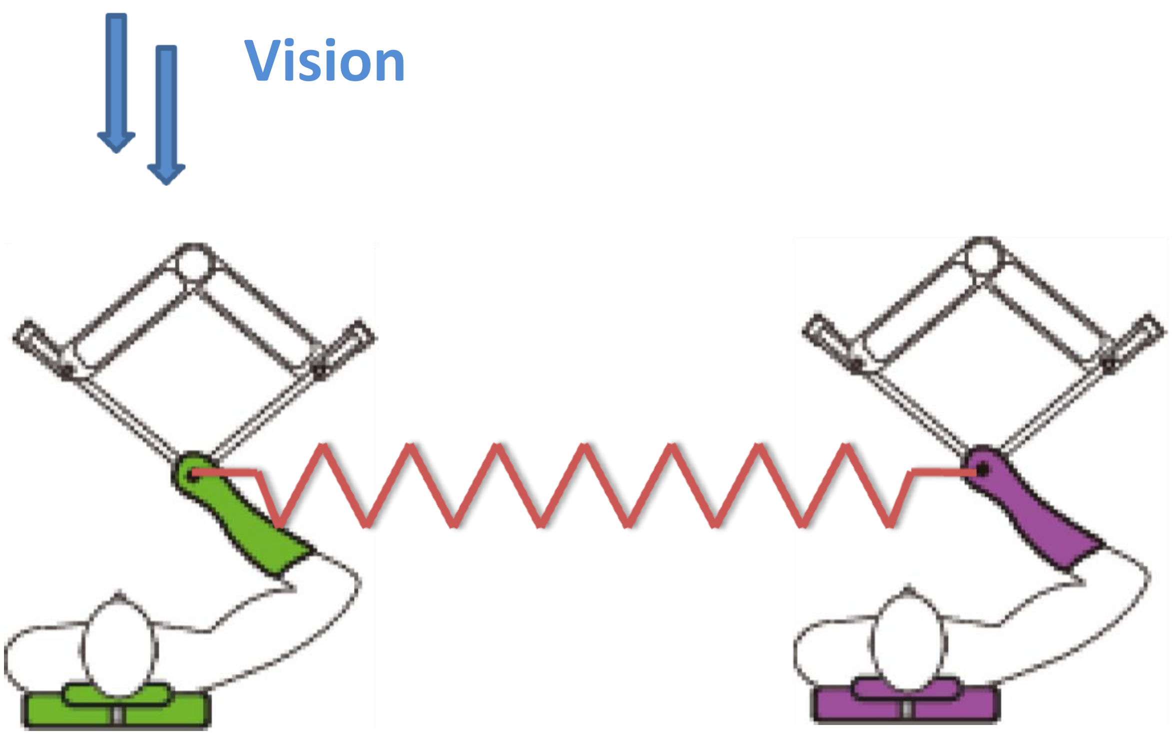


Irrespective of partner performance, interaction leads to performance deterioration

How can interaction benefit both partners?

2. Additional feedback key for benefit?

(sensory integration)



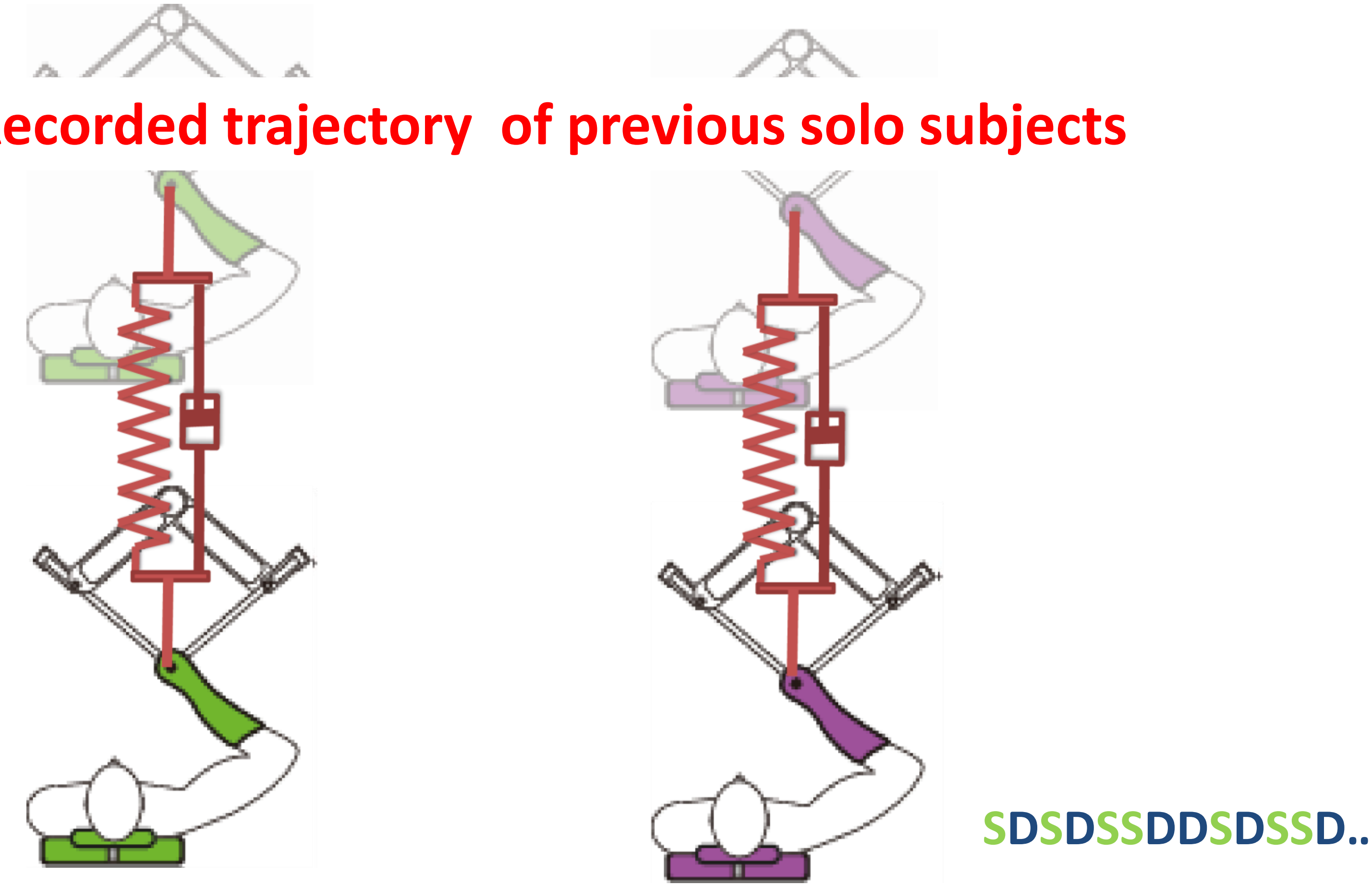
If humans are simply integrating feedbacks:

Any extra feedback related to task error should help in better performance

How can interaction benefit both partners?

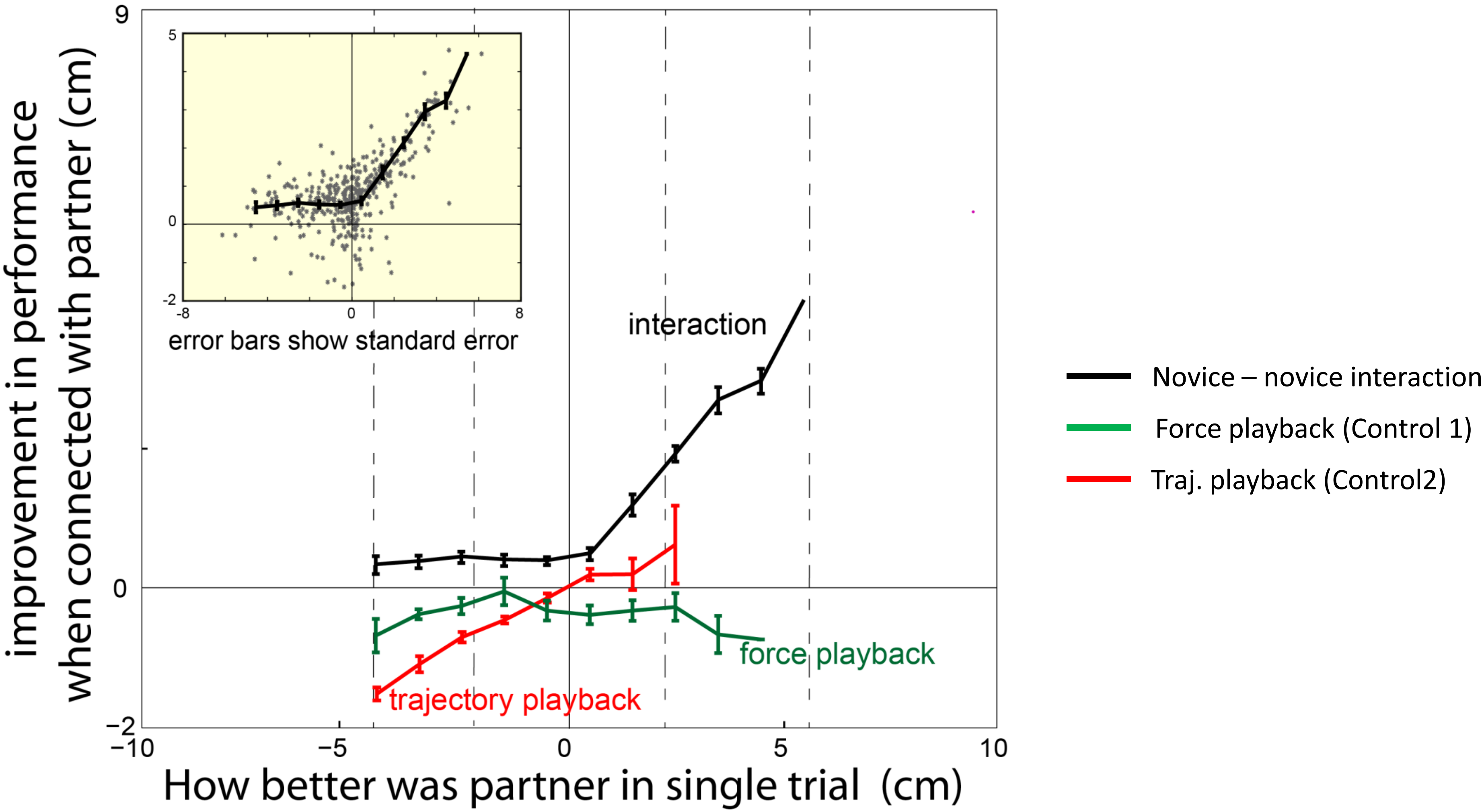
2. Additional feedback key for benefit? (sensory integration)

Recorded trajectory of previous solo subjects



•Control experiment 2- with recorded subject trajectory

Control2: trajectory-playback

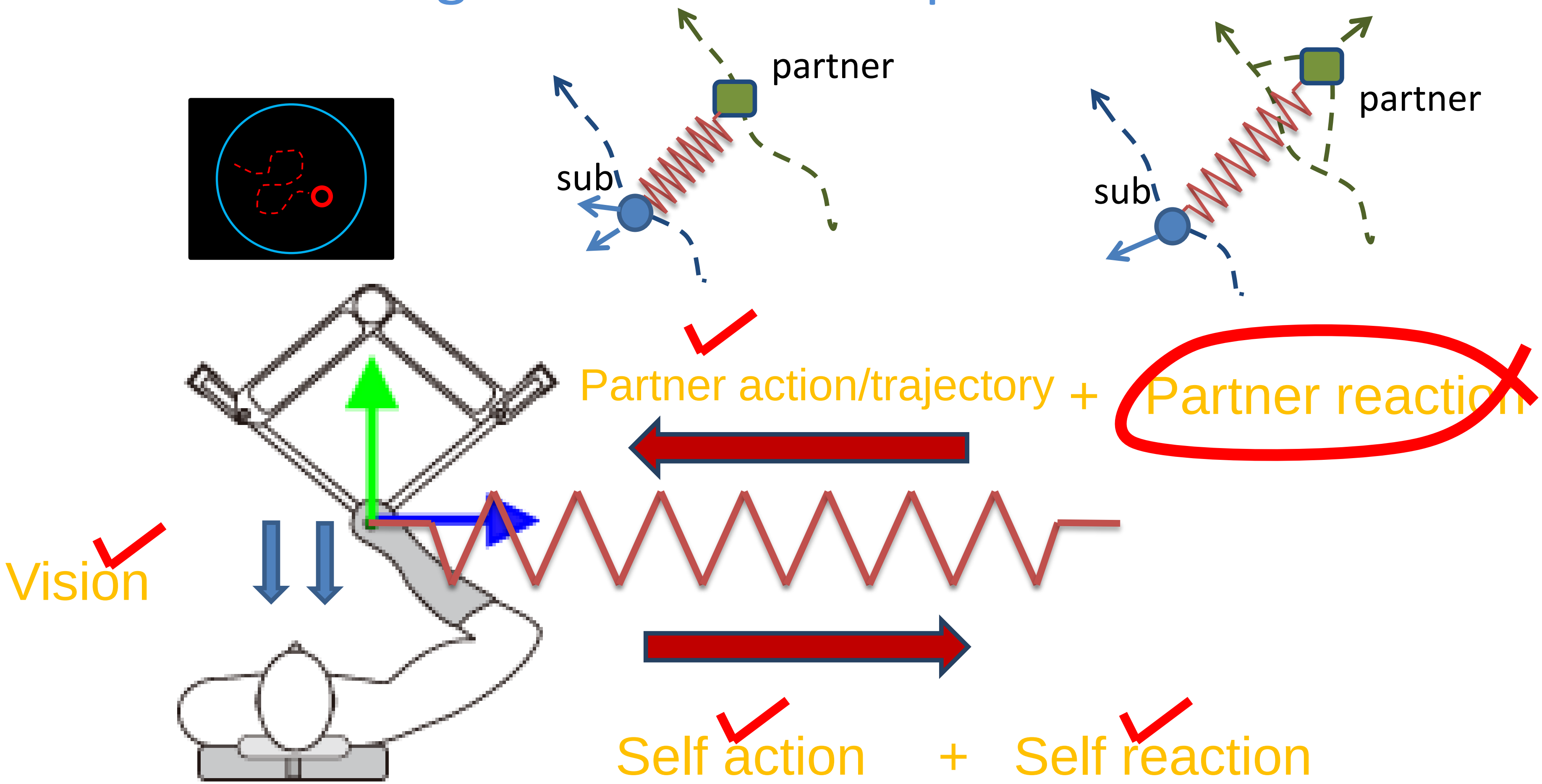


Performance better only if partner is better

How can interaction benefit both partners?

What does interaction consist of? and

What was missing in the control experiments?



Humans expect some specific *partner reaction* during interactive tasks

Counterchecking humans expect a reaction

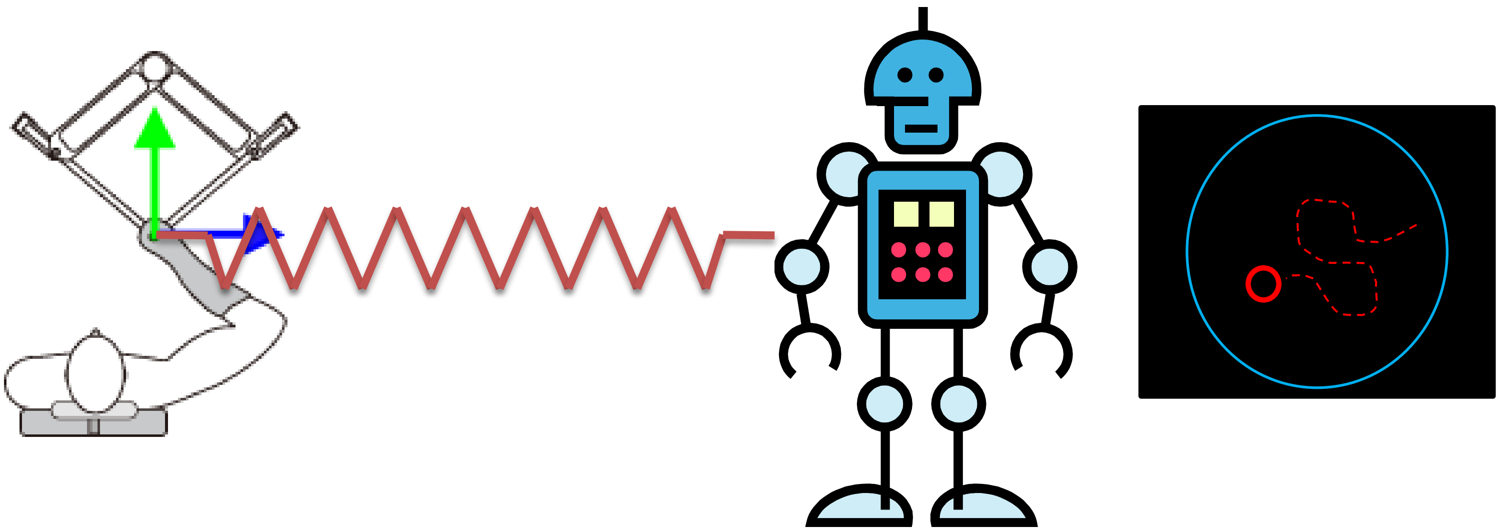
Question:
What kind of partner reaction do individuals expect?

Simulation theory of TOM [Csibra 2007, Gallesse 1998]:
Humans understand intentions of others by simulating the current factors with their own system.

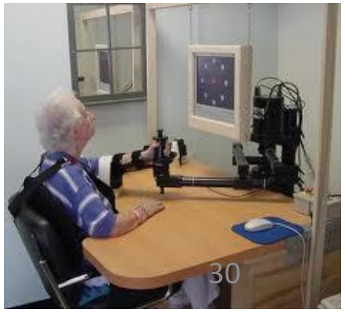
Hypothesis:
Humans model the partner to be similar to themselves

- We can change reaction and see if behavior is affected

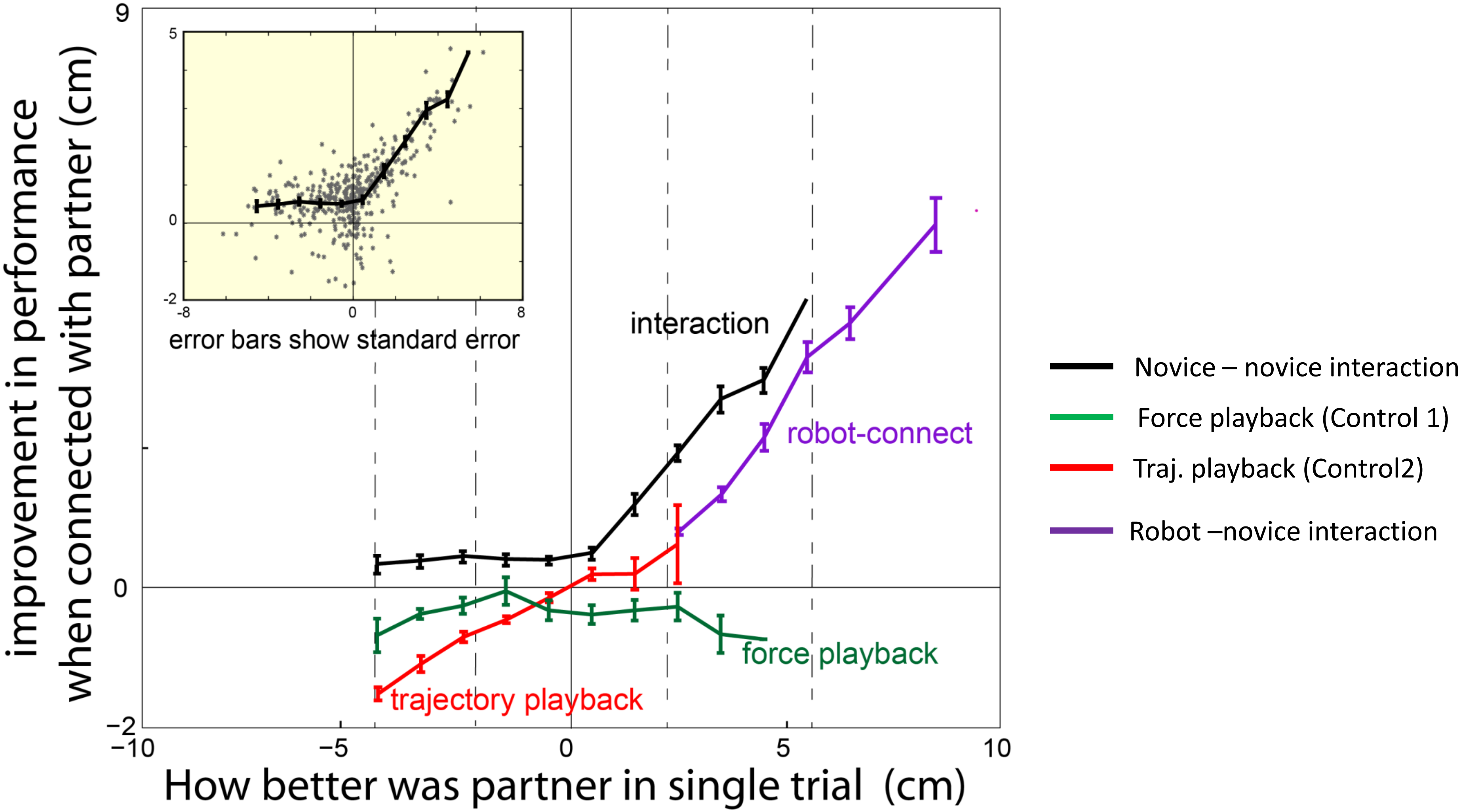
Qualitative reaction change : Connection to non-human agent



- hand connected to a robot that tracks the target perfectly
- 'optimal guidance' but No reaction
- similar to that used in many current rehab applications

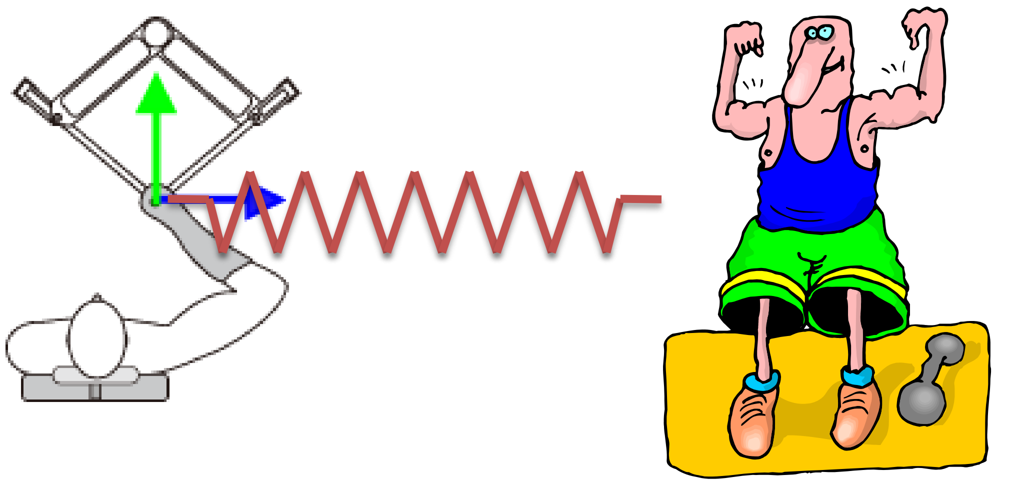


Expert-connect



Performance with robot relatively worse than connection with novice!

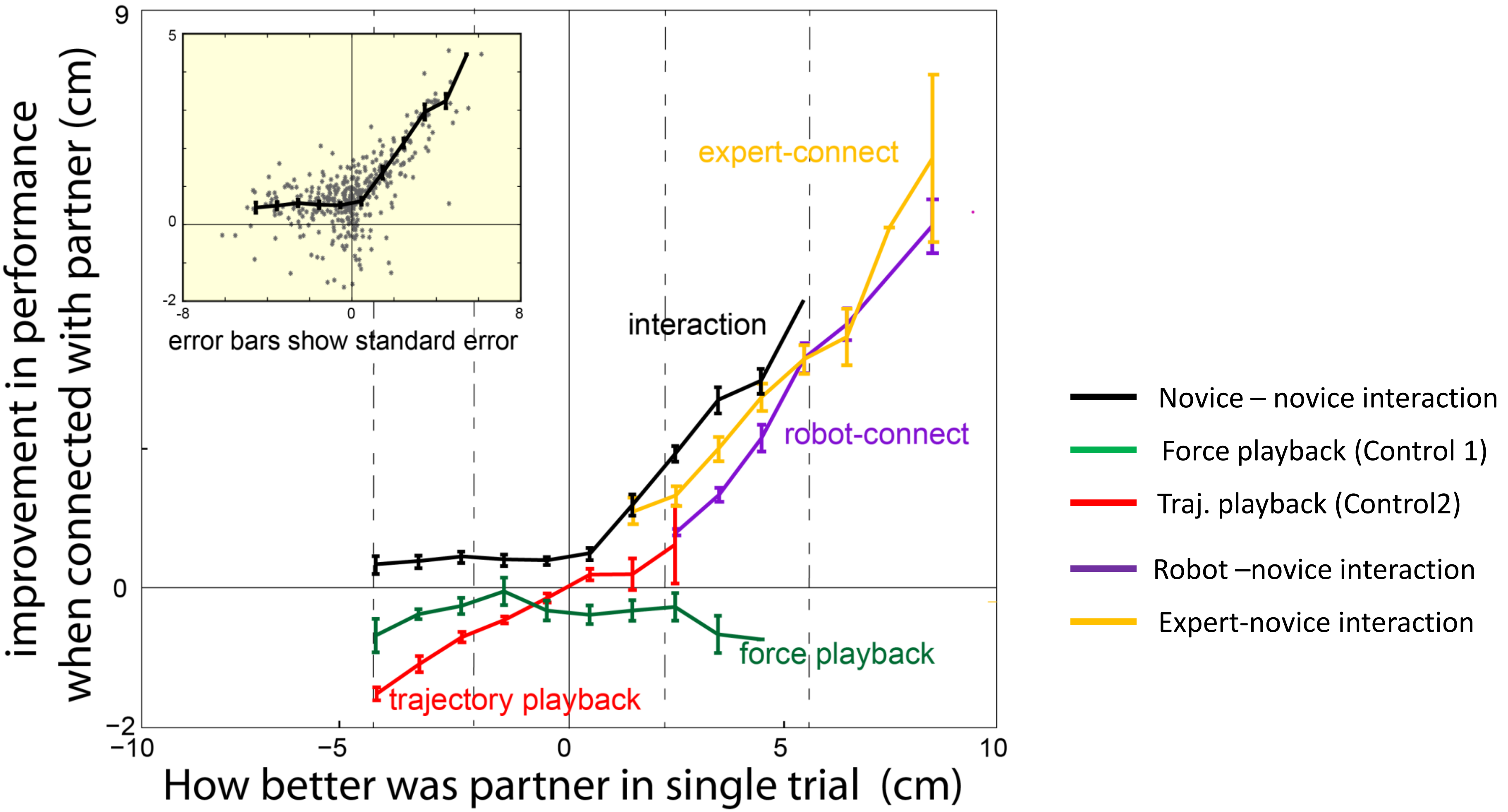
Qualitative response change : Connection with human expert



The difference in skill-level of the expert should produce a qualitative change in the partner response..

So connecting to novice should be better than connection to expert!!

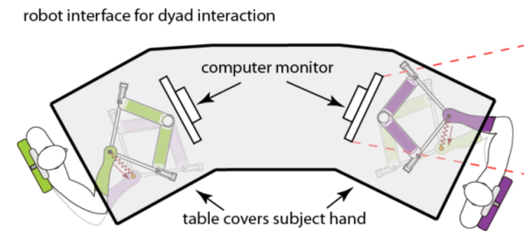
Expert-connect



Similar human > different human (even expert) > non human agent

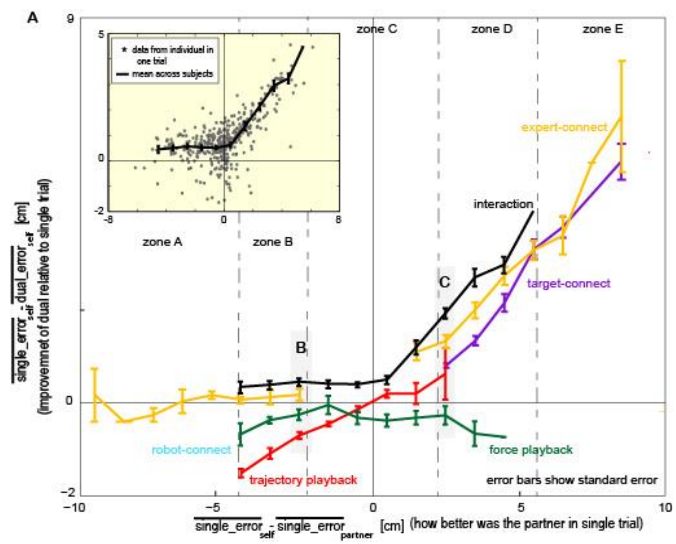
Both partner performance and nature effects mutual benefit

To Summarize



- We designed a human-human interaction experiment to understand how humans share control, how this affects their behavior

- Interaction can enable performance improvement *during* and *after* interaction irrespective of partner performance (mutual benefit)
- Mutual benefit present only when the partner actively tracks target (action) AND provides a appropriate reaction



What did we learn for the improvement of human-robot interactions?

Towards optimal Human-Robot control sharing





- Robots need to actively perform the task in parallel to human
- Robots need to 'consider' human actions-provide online reactions
- Current robots provide Guidance or support (action)

Can we design a robot behavior with these properties?

Answering the Neuroscience questions




- Does TOM act at low level of motor control? Such that we have an internal models of the interaction?

Yes

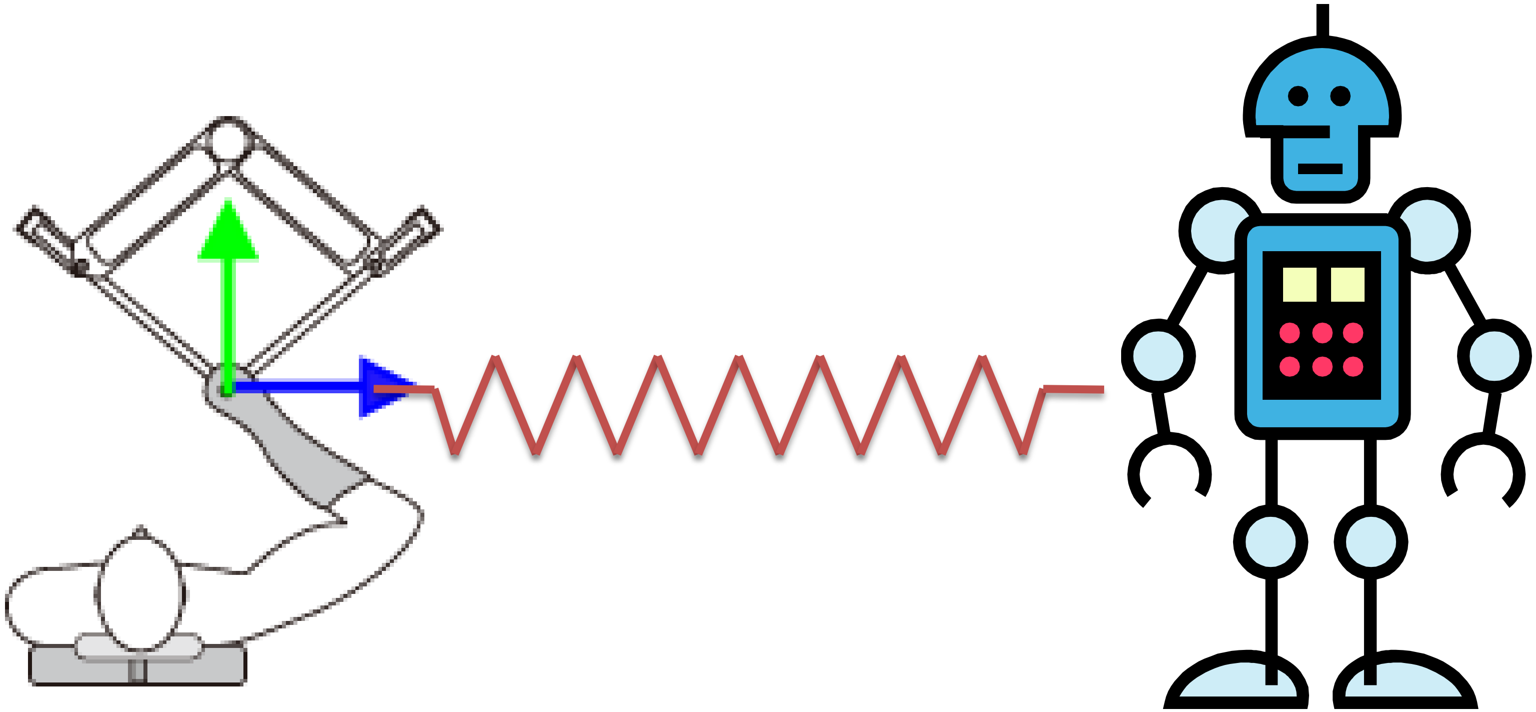
- Does our CNS recognize an interacting agent to be human? Does it influence its behavior?

Yes, behavior is best with similar human

- What is are the neural mechanisms underlying physical interactions?

We do not know how humans use the partner reaction to improve performance….

BUT we know what kind of reaction and behavior enables mutual benefit!!



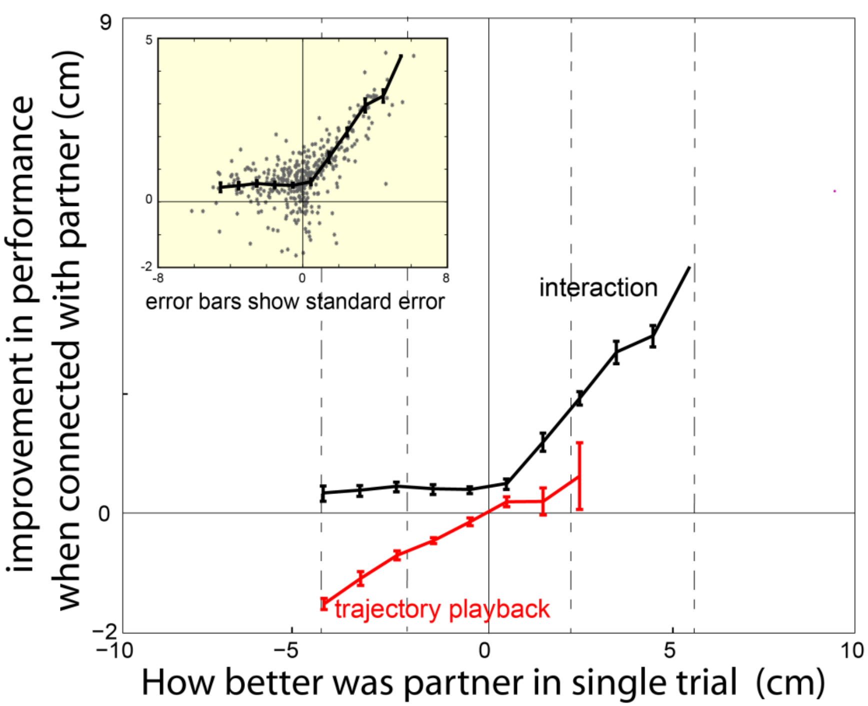
Human performing task

Robot performing task and giving reactions to human behavior and modifying its own behavior with human reactions

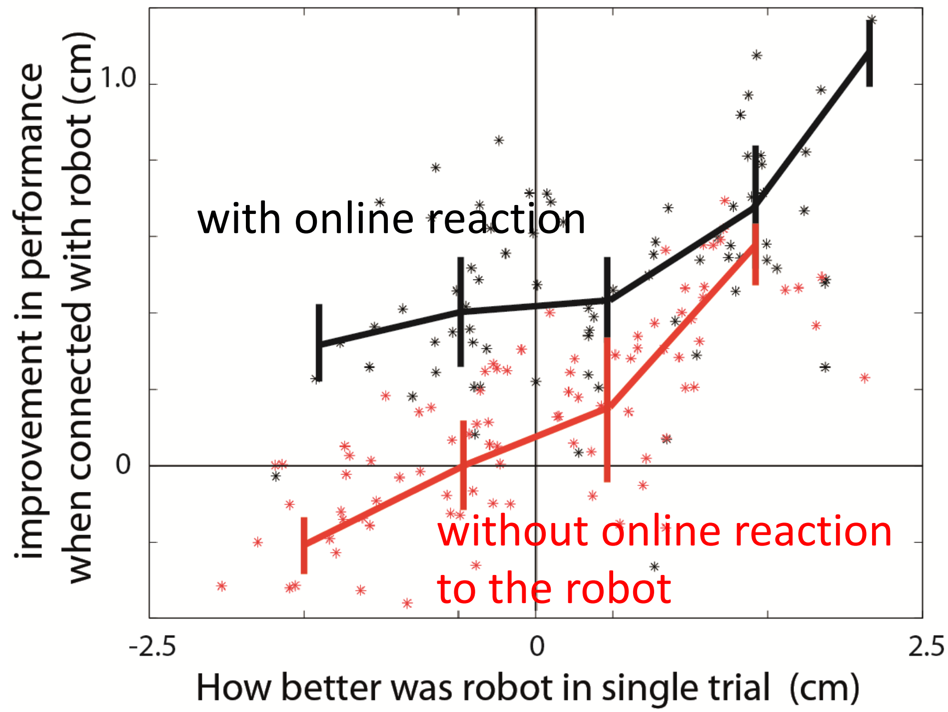
We designed a robot behavior with the algorithm

We get human like benefit with robot!

Human as partner

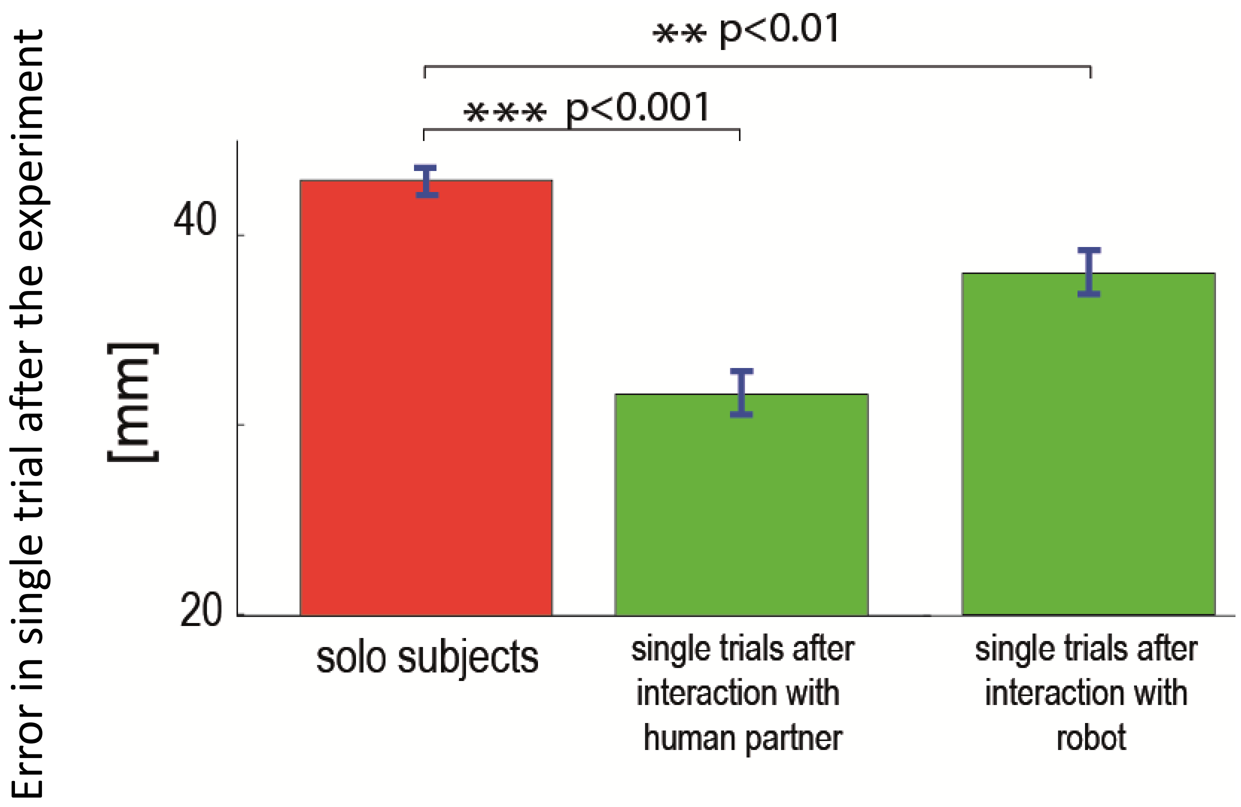


robot as partner



- Human performance consistently better with robot compared to working alone!
- Human performance alone better AFTER interactive practice with robot compared to solo practice of task for the same time

Learning: subjects skill improves by interaction



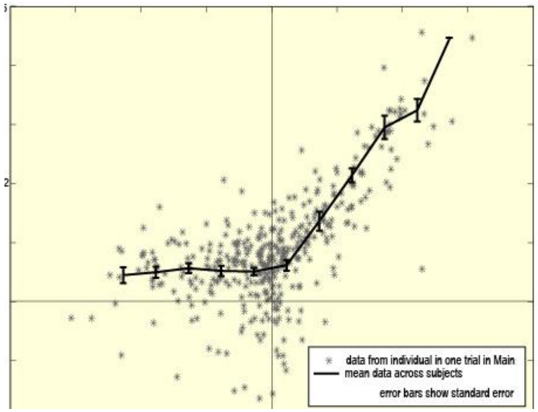
Solo subject: train for the same time but never get connected to a partner

Concluding remarks

- Designing for control : Machines/ Robots can be improved tremendously by considering human movement control

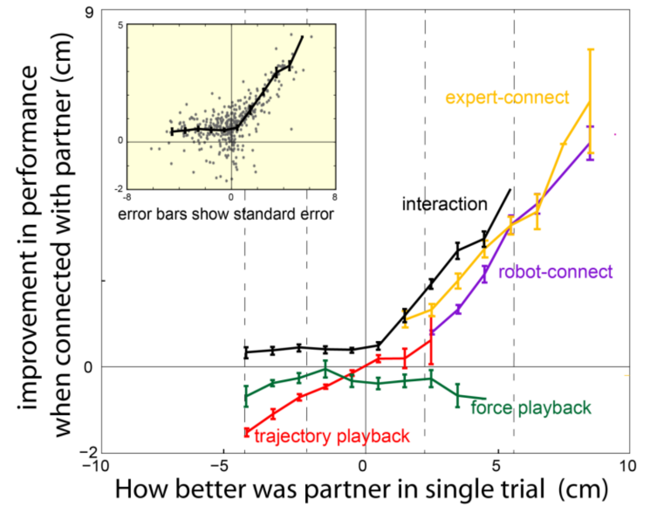
- This requires parallel and comprehensive research in robotics and human motor neuroscience- Human Centric Robotics

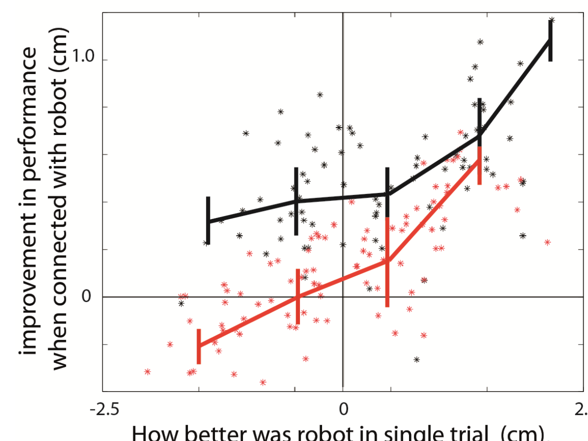
- Example of Human Centric Robotics :
  - Psychophysical human- human interaction experiment
  - Discovered that humans can show mutual performance improvement in interactive tasks!



Concluding remarks

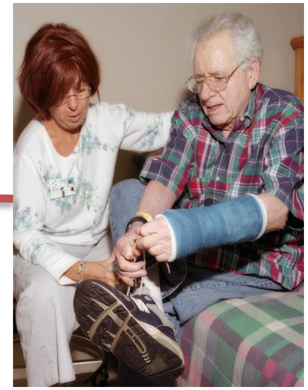
- Example of Human Centric Robotics :
  - Through experiments we isolated the key features that make this possible
  - We implemented this on robots to show similar (improved) human behavior during interactions with a robot





An illustration of the application of mechanical engineering, robotics, logic to understand the human system and improve human-robot interactions

Dual Rehabilitation/training



- Cheaper , subjects can get more physiotherapy time and motivation

•Occupational training can be revolutionized

•Sports training can be revolutionized

This may explain what children learn when they play with other children (rather than with adults)

Example works in Human centric design and robotics

Human motor interactions

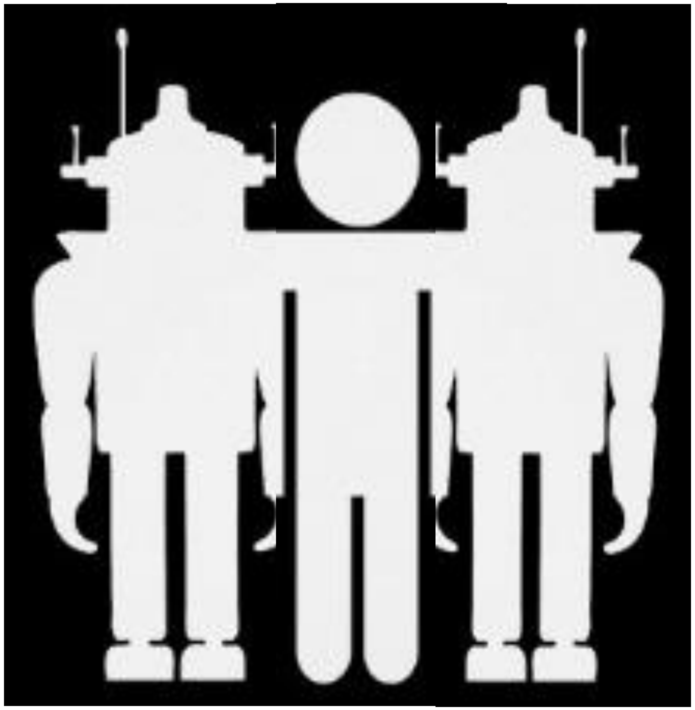
- Mechanisms of physical interaction in humans. Ganesh et al. Nature Sci. Rep. 2013.
- Investigation of the hierarchical organization of human movement learning
- Understanding human behavior during collisions and impact tasks.

Machine-Human interactions

- Intelligent prosthetics project (with New castle Univ.) Pistohl et al. IEEE Rehab Eng. 2014
- Human optimization of hitting tasks and application to robotics (with TUMunich) **Funding JST(JAPAN) and DFG (Germany)**
- Improving BMI with machine learning and neuroscience – with Dr. Miyawaki of UEC Tokyo **Kakenhi 'Houga'.**
- Optimizing design of golf gloves by understanding human motor control.

Cognitive factors during interaction

- Understanding motor control deterioration due to anxiety. **Funding from Kakenhi Kiban B**
- Understanding how motor observation affects ones own motor performance. Ikegami & Ganesh Nature Sci. Rep. 2014
- Immediate Tool induced effect on human body representation. Ganesh et al Nature Com. 2014.
- Embodiment issues in humanoid avatars.



Thank you

Human Centric Robotics

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