ISTITUTO DI TECNOLOGIE DELLA COMUNICAZIONE, DELL'INFORMAZIONE E DELLA PERCEZIONE

PERCRO Perceptual Robotics Laboratory

Scuola Superiore Sant'Anna

Introduzione alla robotica

Antonio Frisoli

PERCRO, Scuola Superiore Sant'Anna

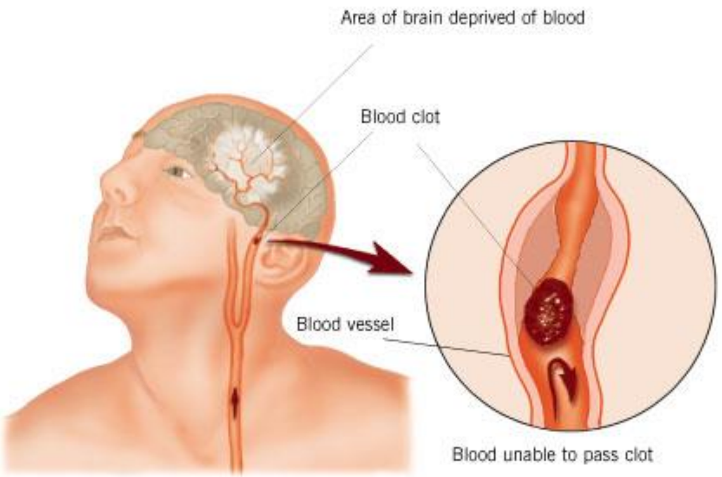
Strokes may be one of two types:

- **Ischemic stroke:**

  The vast majority of strokes, estimated at 80%, are of the ischemic type. Ischemic stroke involves a constriction of blood supply to the brain, causing an interruption in the oxygenation of brain cells.
  - **The most common is thrombosis, in which a blood clot restricts or cuts off the flow of blood to a part of the brain.**
  - **Ischemic stroke can also be caused by embolism, which occurs when a blood clot breaks off or another piece of debris enters the blood stream, thus blocking the flow of blood.**

- **Hemorrhagic stroke (also called cerebral hemorrhage,**

  Hemorrhagic stroke is characterized by the rupture of a blood vessel or severe damage to the head, which also causes an interruption in blood supply, while the flood of blood irritates and damages tissue. Hemorrhagic strokes are potentially far more deadly because of their rapid onset and the severe damage that can occur in a short period of time from the rupture of an aneurysm or venous malformation..



The impairment of upper limb function is one of the most common and challenging sequelae following stroke, that limits the patient's autonomy in daily living and may lead to permanent disability. The deficits are characterized:

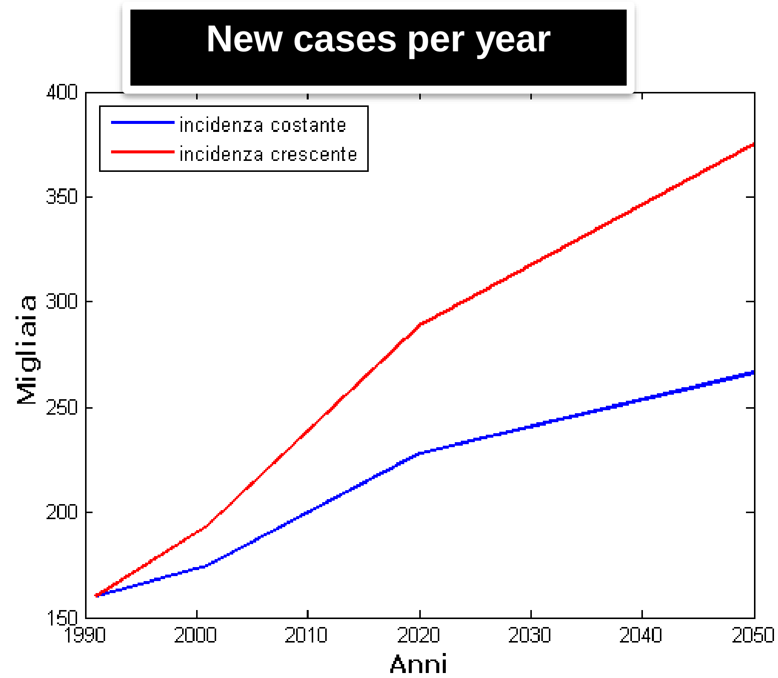
- **Weakness of specific muscles**
- **Abnormal muscle tone**
- **Abnormal postural adjustment**
- **Abnormal movement synergies**
- **Incorrect timing of components within a movement pattern**

Neurorehabilitation aim is the recovery of the lost capabilities

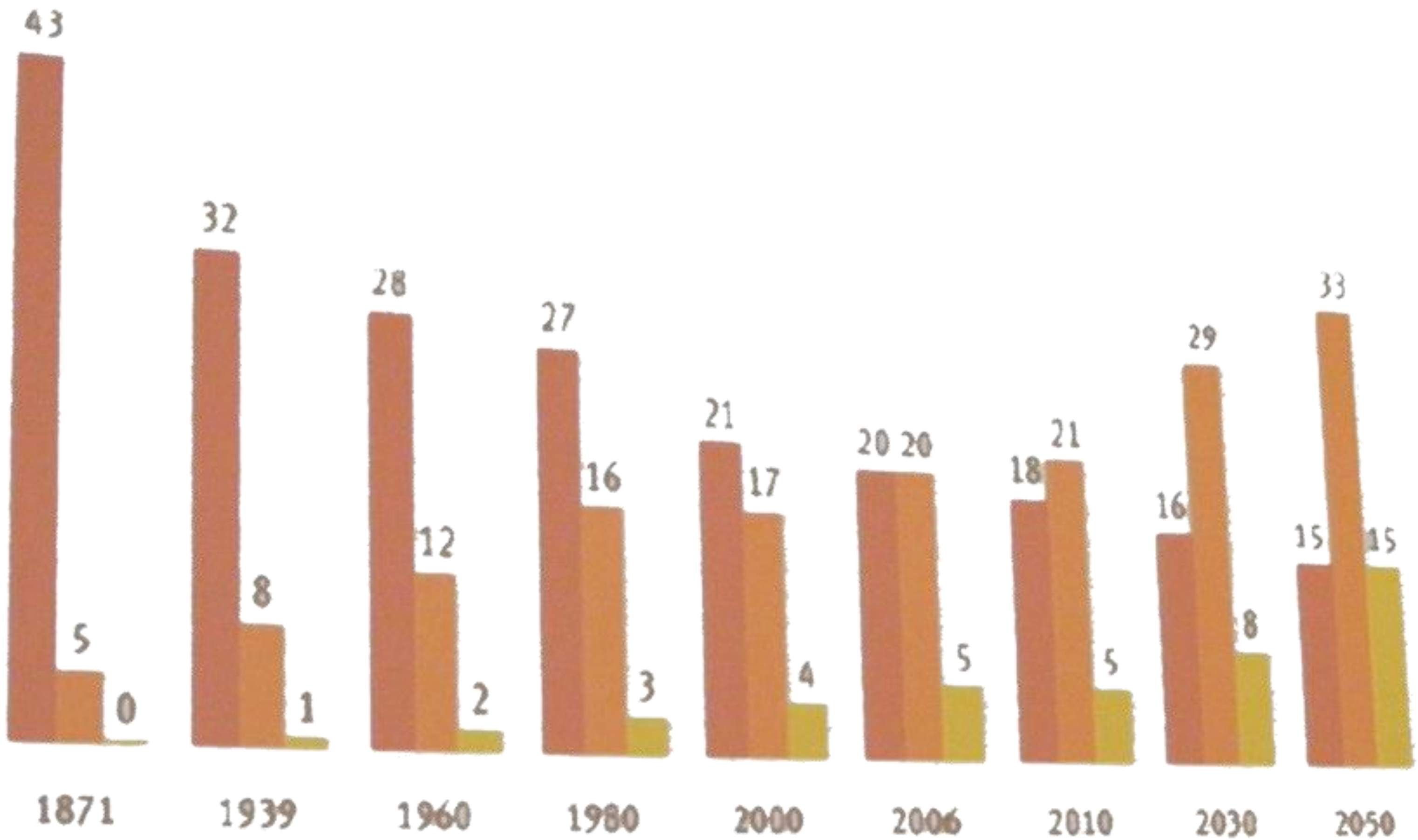
- It is not only a physical therapy, it is a real learning process, since it involves re-learning of motor strategies at neural central level.

Some statistics

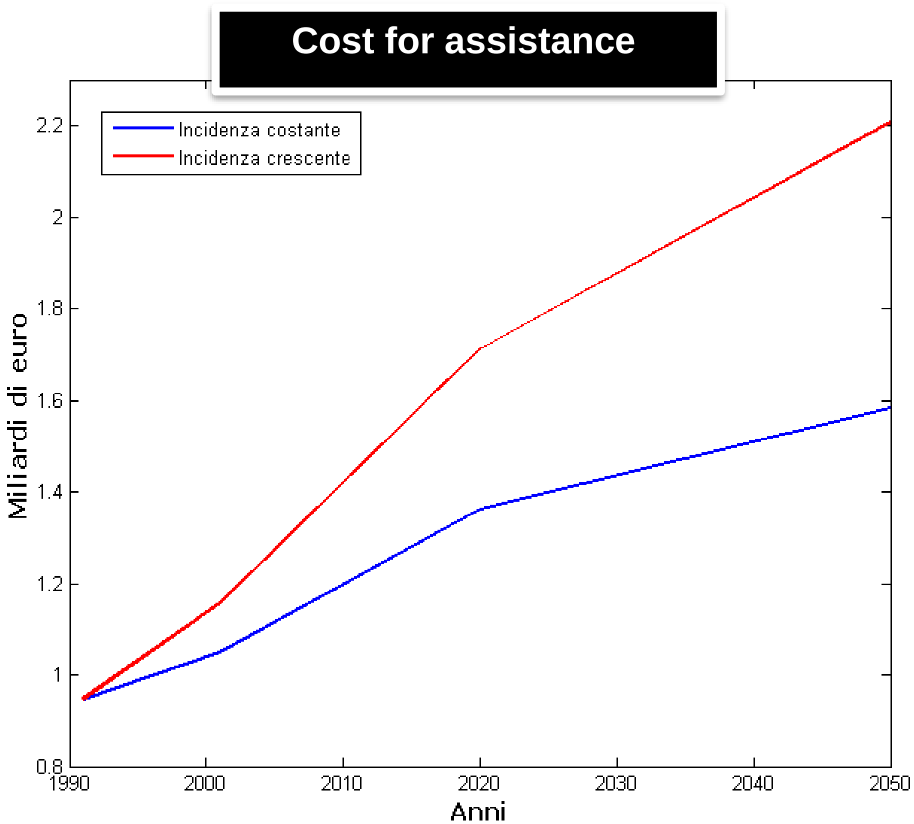
- Cerebrovascular disease is the third leading cause of death in industrialized countries and the leading cause of permanent disability.
  - In Italy, about 915,000 people were affected b stroke.
  - About 30% of these reported disabling outcomes, including the most frequent is the paralysis of the upper limbs
- The aging population and increased incidence of cerebrovascular disease involves a continuous increase in the number of new cases per year.



An aging population



Population under 20
Population over 65
Population over 80



- There is therefore a considerable increase in hospital costs
- However, these costs represent only 20% of the total cost for the management of patients with stroke also including indirect costs resulting from lost productivity of family and patient.
- Importance of treatment not only at time of event, but also later on.

A. Carolei, C. Marini, M. Baldassarre. Proiezioni statistiche e previsioni dei costi dell'ictus Clinica Neurologica, Università degli Studi di L'Aquila, L'Aquila

Main applications of active exoskeletons

- Rehabilitation
  - Stroke patients are requiring to achieve better and better motor recovery. The motor consequences typically include three major aspects:
    - loss of control over muscles (hemiparesis),
    - emergence of muscle contractions and spams (spasticity)
    - disruption of coordination in motor actions,including reaching and grasping
- Robotic technology is mature for usage, possible coupling with VR:
  - **Active and highly repetitive movements performed;**
  - Rehabilitation trial is better controlled and objective analyzed by therapist;
  - Efficacy of VR rehabilitation approach proven by several studies
- Technology is mature for usage, possible coupling with VR
  - Recent evidences suggest that, following a period of rapid sensorimotor recovery in the first three months after stroke, improvement occurs more gradually for a period of up to two years and perhaps longer.
  - Several studies have attempted to investigate the efficacy of stroke rehabilitation approaches;
  - High-intensity and task specific upper limb treatment consisting of active, highly repetitive movement is one of the most effective approaches to arm function restoration.

Stroke and its effects

- Speech
- Movement
- Memory
- View
- Behavior

- Swaffield, Thorsons 1996
- Skilbeck et all, Journal of Neurology, Neurosurgery & Psychiatry 1983
- Stason et all, Diane Publishing Company 2014

Specifics of an effective rehabilitation

REPETITIVE

INTENSIVE

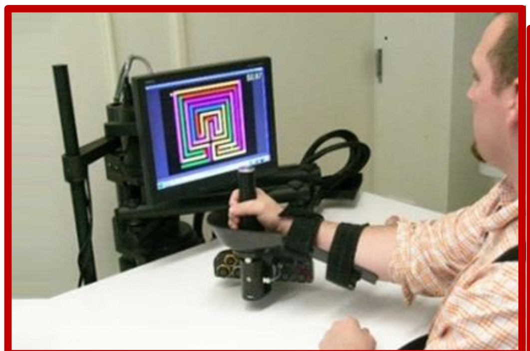
LONG TERM

SPECIFIC

- Bütefisch et all, Journal of the neurological sciences 1995
- Kwakkel et all, The Lancet 1999
- Sunderland et all, Journal of Neurology, Neurosurgery & Psychiatry 1992

Neuro-motor rehabilitation in stroke

- Hemiparesis of upper extremity represents a common impairment affecting patients after *stroke*
- American Heart Association estimates that it affects approximately 795 000 people in the U.S. each year
- New robotics interfaces for rehabilitation can overcome some of the major limitations in the traditional assisted training movement:
  - repeatability
  - factors for assessing progress
  - availability of skilled personnel



MIT Manus, *(Hogan et al., 1992)*

L-Exos *(Frisoli et al., 2005)*

Armin, *(Nef and Riener, 2005)*

Armeo

commercially available replica of the T-WREX (Sanchez et al., 2005)

Two factors that play a relevant role in the process of motor recovery

- However, it is not movement per se, obtained for example by means of **passive mobilization**, which is effective in recruiting **plastic adaptation**
- **The key is: movement training associated with a task and volitional effort**
  - **Functional recovery implies active movements…**
  - **& Task oriented training**

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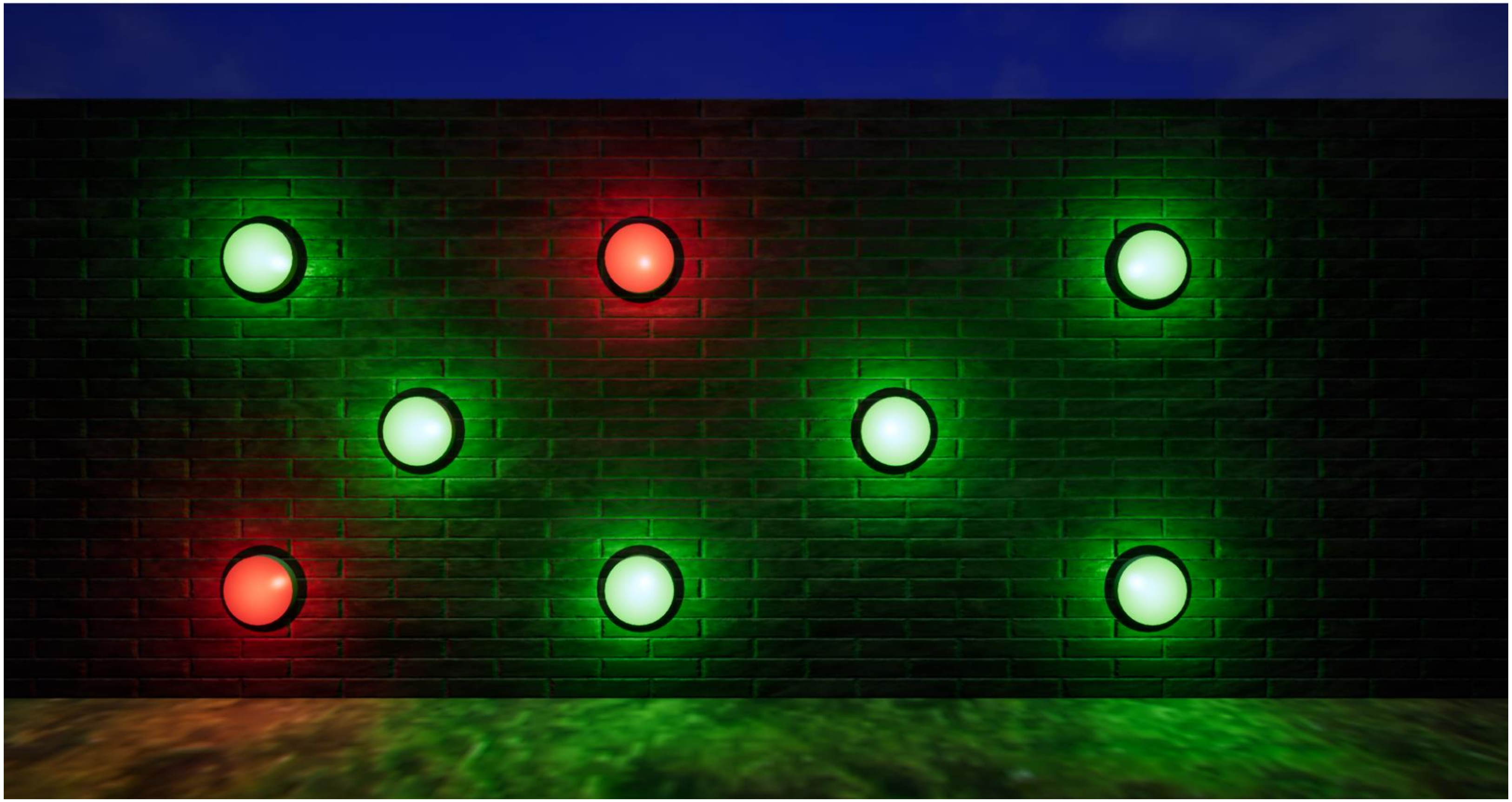
Esempio di task-oriented exercise

Serious Game: CIRCLE WALL



Serious Game: LIBRARY

Serious Game: COFFEE TABLE

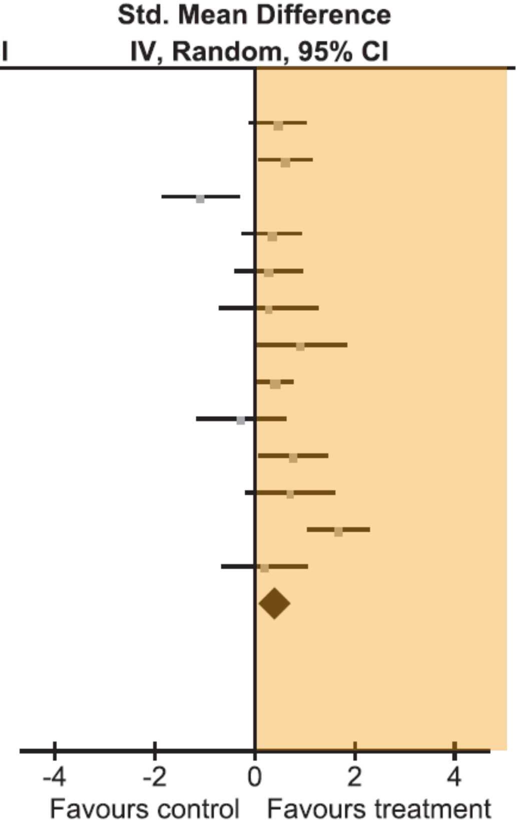
Review update

- Patients who receive electromechanical-assisted arm training after stroke are more likely to improve their generic activities of daily living and may improve arm function.
- The findings indicate, however, that motor strength of the paretic arm is not more likely to improve when patients after stroke train with electromechanical devices or robots.

	Treatment			Control				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
1.1.1 All studies								
Burgar 2011	19.6	8.47	36	15.9	6.36	18	8.9%	0.46 [-0.11, 1.04]
Conroy 2011	3.98	11.94	41	-3.19	10.72	21	9.2%	0.61 [0.08, 1.15]
Fazekas 2007	12.07	9.26	15	25.53	14.32	15	7.2%	-1.09 [-1.86, -0.31]
Hesse 2005	22.45	15.14	22	17.27	13.95	22	8.7%	0.35 [-0.25, 0.95]
Houseman 2009	0.2	0.4	17	0.1	0.3	17	8.0%	0.28 [-0.40, 0.95]
Hsieh 2011	0.13	0.19	12	0.06	0.32	6	5.7%	0.28 [-0.71, 1.27]
Liao 2011	0.25	0.17	10	0.03	0.28	10	6.1%	0.91 [-0.02, 1.84]
Lo 2010	6.31	11.76	49	1.37	12.1	78	10.6%	0.41 [0.05, 0.77]
Lum 2006	2.85	1.21	24	3.2	1.4	6	6.3%	-0.27 [-1.17, 0.62]
Masiero 2007	32.6	7.2	17	25.5	10.5	18	7.9%	0.77 [0.08, 1.46]
Masiero 2011	1.83	1.4	11	1	0.7	10	6.4%	0.71 [-0.18, 1.60]
Volpe 2000	9.1	3.3	30	4.4	2	26	8.5%	1.67 [1.05, 2.29]
Volpe 2008	67.1	7.96	11	65.5	7.59	10	6.6%	0.20 [-0.66, 1.06]
Subtotal (95% CI)			**295**			**257**	**100.0%**	**0.43 [0.11, 0.75]**

Heterogeneity: $Tau^2 = 0.22$; $Chi^2 = 35.99$, df = 12 ($P = 0.0003$); $I^2 = 67\%$

Test for overall effect: Z = 2.60 (P = 0.009)



Mehrholz J, Hädrich A, Platz T, Kugler J, Pohl M. Electromechanical and robot-assisted arm training for improving generic activities of daily living, arm function, and arm muscle strength after stroke. Cochrane Database Syst Rev. 2012;

Vantaggi della terapia robotica

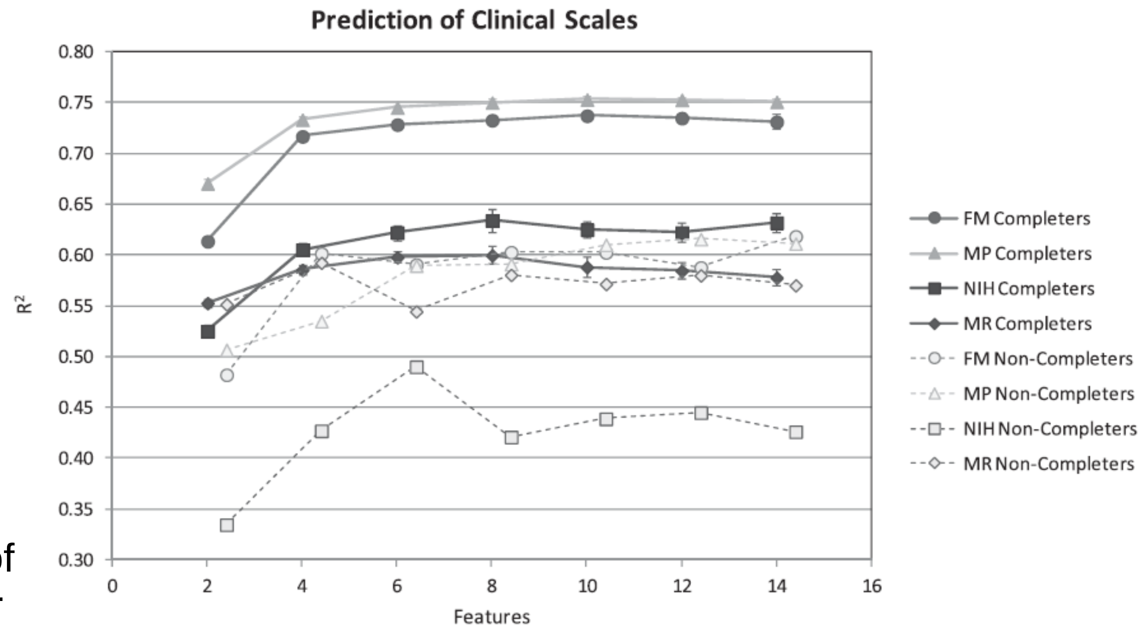
- Equivalenza tra terapia robotica e terapia manuale intensiva
  - Maggiore intensità di seduta
  - Elevata ripetibilità e standardizzazione
- Motivazione
  - Coinvolgimento attivo del paziente grazie alla proposta in realtà virtuale/computer game
  - Approccio task-oriented nell'esecuzione dell'esercizio motorio
  - Feedback sulla prestazione o risultato
- Modulazione dell'assistenza, valutazione automatica
  - Modulazione dell'aiuto in funzione dell'esigenza del paziente
  - Quantificazione oggettiva ed analitica del recupero motorio

Krebs et al, Robot-Assisted Therapy for Long-Term Upper-Limb Impairment after Stroke, N Eng J Med 2010

Vantaggi della terapia robotica

- Quantificazione oggettiva ed analitica del recupero motorio mediante
  - Acquisizione di parametri cinesiologici e cinetici
  - Correlazione statistica con scale cliniche

- robotic devices record the kinematics and kinetics of human movements with high resolution,
- robotic measures collected longitudinally in patients after stroke would bear a significant
- relationship to standard clinical outcome measures and, therefore, provide superior biomarkers
- Among 208 patients, robotic measures predicted well the clinical measures (cross-validated R2 of modified Rankin scale=0.60; National Institutes of Health Stroke Scale=0.63; Fugl-Meyer=0.73; Motor Power=0.75).

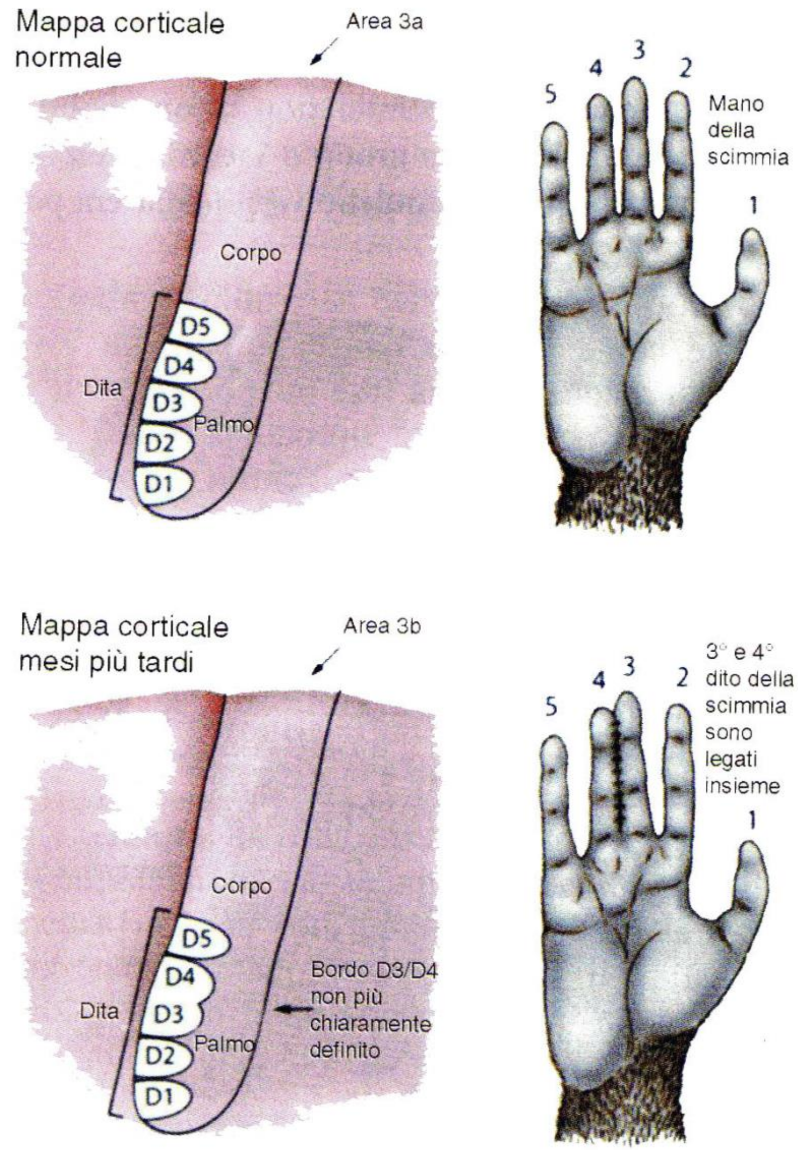


Krebs et al, Robot measurements after stroke establishes biomakers of motor recovery, Stroke 2014

Neuroplasticity

- Neuroplasticity refers to the changes that occur in the organization of the brain, and in particular changes that occur to the location of specific information processing functions, as a result of the effect of experience during development and as mature animals.
- A common and surprising consequence of brain plasticity is that the location of a given function can "move" from one location to another in the brain due to repeated learning or brain trauma.

- **The plasticity of the CNS is defined by its ability to change.**
- **Even in the post-natal, the CNS may change:**
  - **<u>but</u> the neurons are no longer free to migrate, multiply, or to reconstitute long-distance connections**
  - **You can change the synaptic connections in relation to afferents**



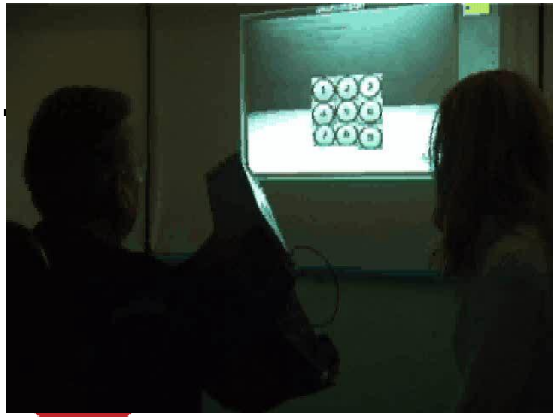
Motion recovery

- The mechanisms of functional recovery after stroke are still largely unknowns

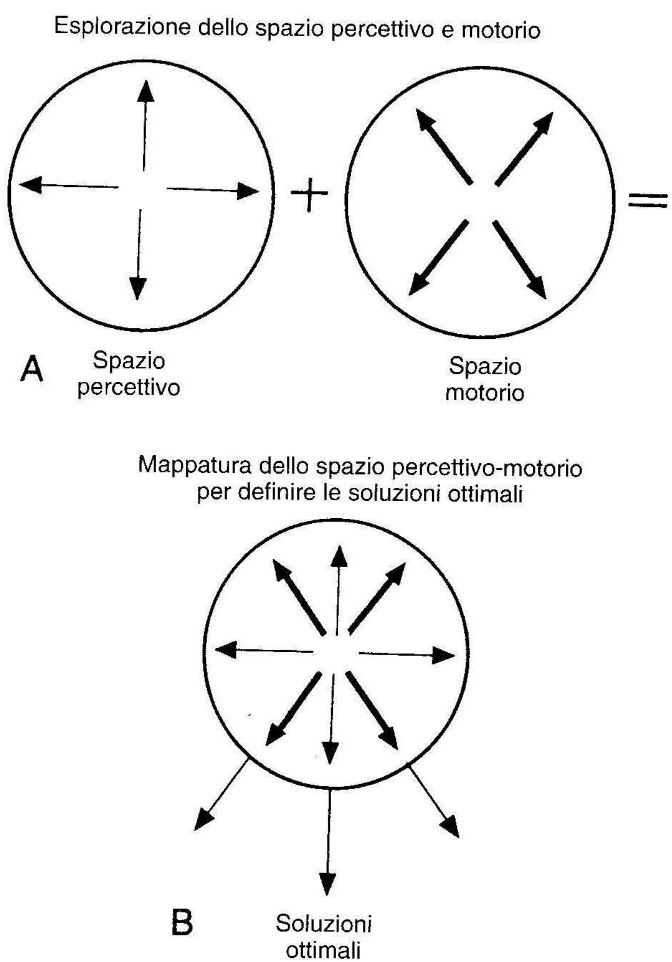
BUT

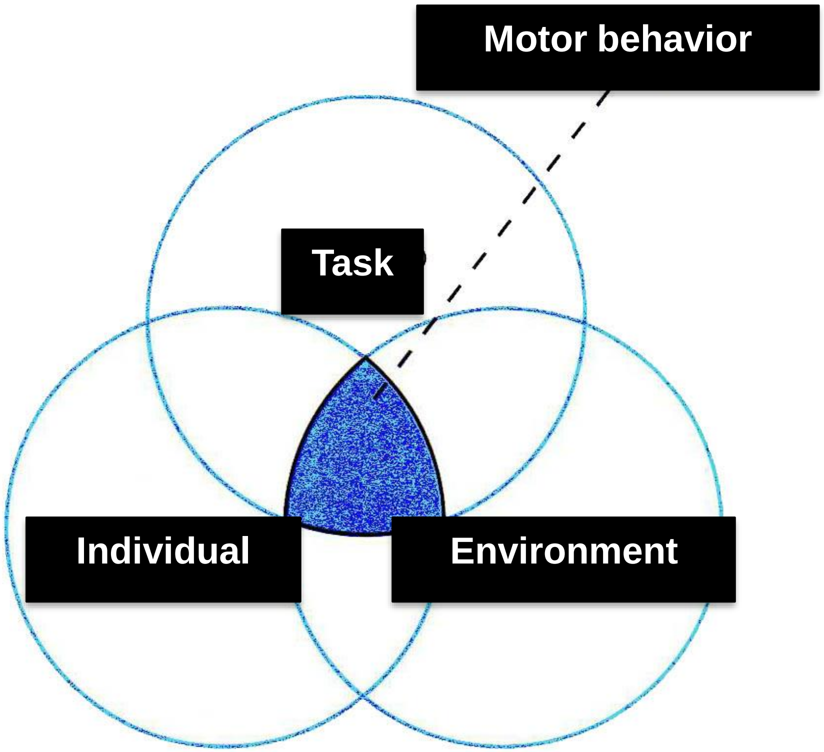
- **Animal models and correlated human studies demonstrate that functional recovery of motor patterns after stroke is obtained through the use-dependent reorganization of neural mechanisms, exploiting basic properties of neural plasticity**

- **However, it is not movement per se, obatained for example by means of passive mobilization, which is effective in recruiting plastic adaptation**
- **The key is: movement training associated with a task and volitional effort**
  - **Functional recovery implies active movements…**
  - **& Task oriented training**

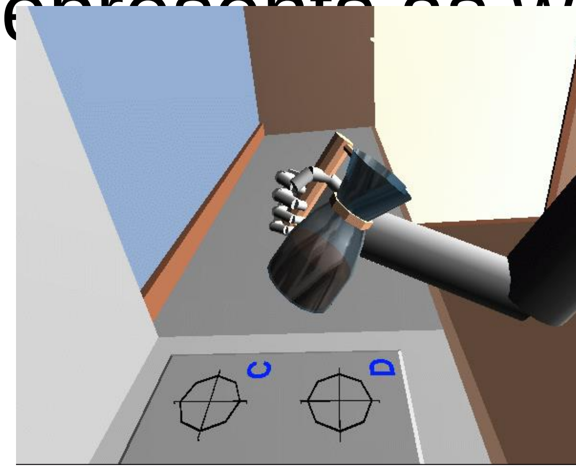


Systemic approach to





Virtual reality combined with robotics represents as well a powerful tool:



"Virtual Reality (VR) provides a unique medium suited to the achievement of several requirements for effective rehabilitation. Specifically, therapy can be provided within a functional, purposeful and motivating context. Many VR applications present opportunities for individuals to participate in experience, which are engaging and rewarding."

Figures adapted from Bergamasco et al 1995

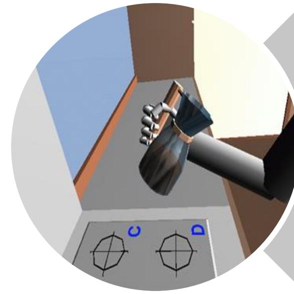
H. Sveistrup, Motor rehabilitation using Virtual Reality, Journal of NeuroEngineering and Rehabilitation, 1 (10), 2004.

Occupational therapy

Therapy in VR

Occupational therapy intervention, such as activities of daily living,

Transfer is associated with perceptual similarities among tasks



Virtual reality offers the possibility to reproduce daily activities and tasks

Transfer leaning (in rehabilitation) refers to a person's ability to carry out the same task in a different environment.

Transfer is not at all-or-none phenomenon
Near, intermediate, far, very far
Based on difference between learning and real-life environment

- **Focus on reaching, fundamental movement involved in every ADL and associated to grasping**
- **Proposal of different exercises with equivalent activities in real-life: 3d puzzle, wiping**

- Patients who receive electromechanical and robot-assisted arm training after stroke are not more likely to improve their activities of daily living, but arm motor function and strength of the paretic arm may improve

	Treatment			Control				Std. Mean Difference
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Random, 95% CI**
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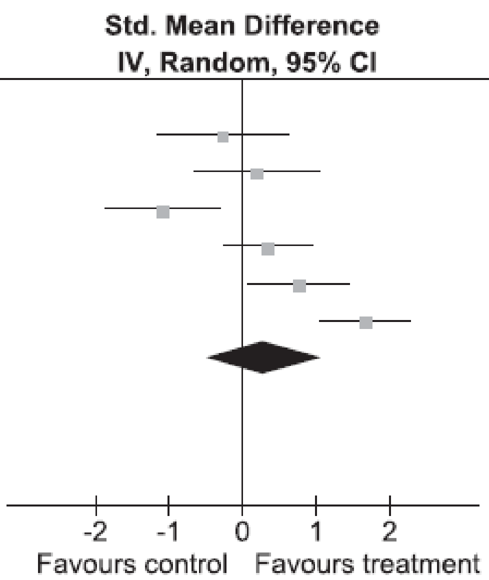
Subtotal (95% CI)			**119**			**97**	**100.0%**	**0.29 [-0.47, 1.06]**

Heterogeneity: Tau² = 0.78; Chi² = 33.96, df = 5 (P < 0.00001); I² = 85%

Test for overall effect: Z = 0.75 (P = 0.45)



As primary outcome it was measured the activity of dailiy living, such as Barthel Index core, Functional Indepedance Measure, the ABILHAND

Mehrholz J, Platz T, Kugler J, Pohl M. Electromechanical and robot-assisted arm training for improving arm function and activities of daily living after stroke. Cochrane Database Syst Rev. 2008

Review update

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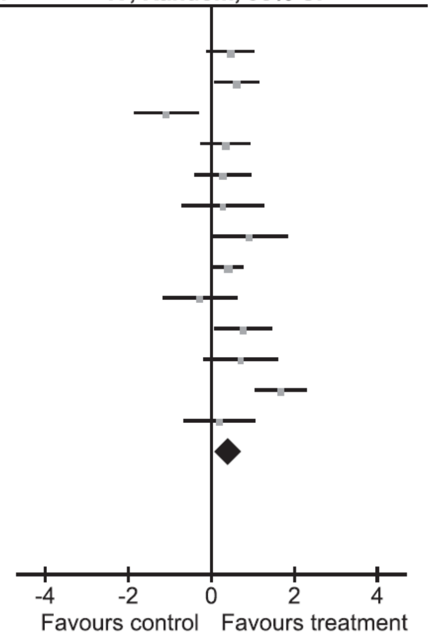


Mehrholz J, Hädrich A, Platz T, Kugler J, Pohl M . Cochrane Database Syst Rev. 2012;

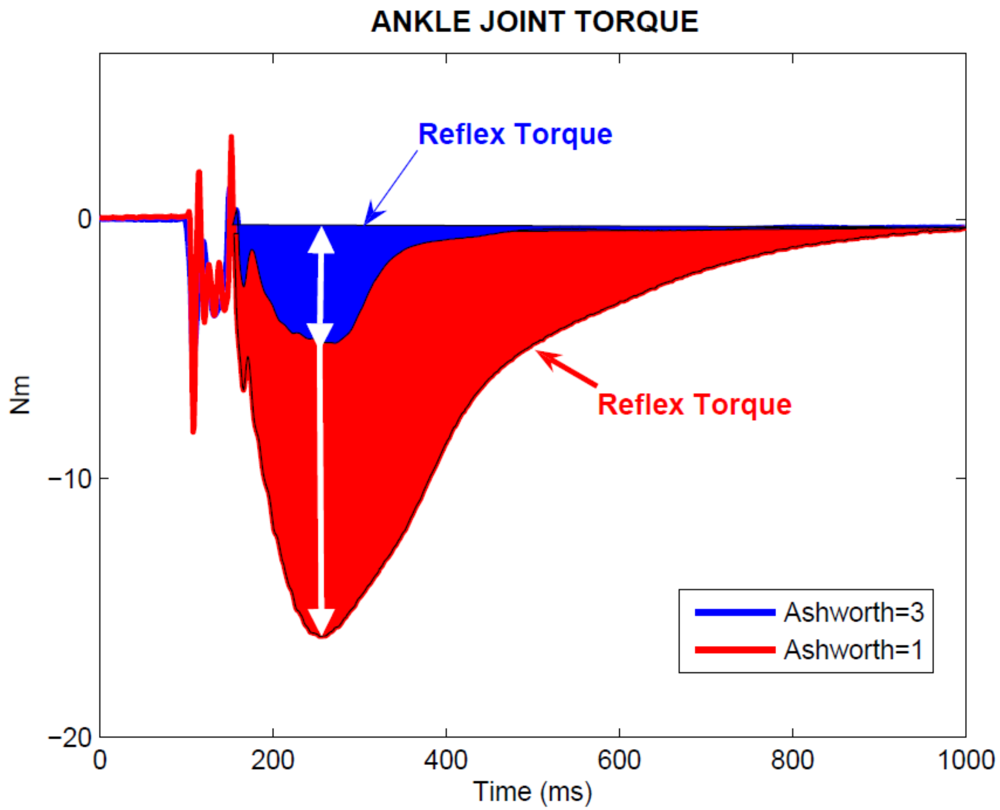
Ashworth Assessment Scale

- Modified Ashworth Scale (MSE) is considered the primary clinical measurement of muscle spasticity in patients with neurological problems.
- However, some publications question on its ability to measure spasticity and criticize the Modified Ashworth Scale as a rating scale to measure abnormalities in muscle tone or resistance to passive movement, since there is no direct method to measure clinical spasticity.
- Although there are no standardized guidelines for use, the Modified Ashworth Scale can be applied to the muscles of both extremities of the body, lower or higher. The evaluator needs to extend the limb of the patient from a position of maximum flexion to full extension until it meets the first little resistance.

The Ashworth scale

Score	Ashworth Scale (Ashworth, 1964)	Modified Ashworth Scale (Bohannon & Smith, 1987)
0	Nessun aumento nel tono	Nessun aumento nel tono
1	Leggero aumento del tono mentre l'arto è spostato in flessione o estensione	Leggero aumento del tono muscolare, manifestato con la presa o il rilascio o da una resistenza minima alla fine dell'escursione nel movimento, quando la parte interessata è flessa o estesa
1+	N / A	Leggero aumento del tono muscolare, si manifesta con una presa, seguito da una resistenza minima per meno della metà dell'escursione nel movimento
2	Più marcato aumento nei toni, ma arto flesso facilmente	Più marcato aumento del tono muscolare attraverso la maggior parte dell'escursione nel movimento, ma si possono facilmente spostare le parti interessate
3	Notevole aumento di tono e movimento passivo difficile	Notevole aumento del tono muscolare, il movimento passivo risulta difficile
4	Arto rigido in flessione o estensione	La parte interessata risulta rigida in flessione o in estensione

- Example of ankle joint torque induced by the stretch reflex into two patients with stroke and different degree of impairment measured by means of MAS

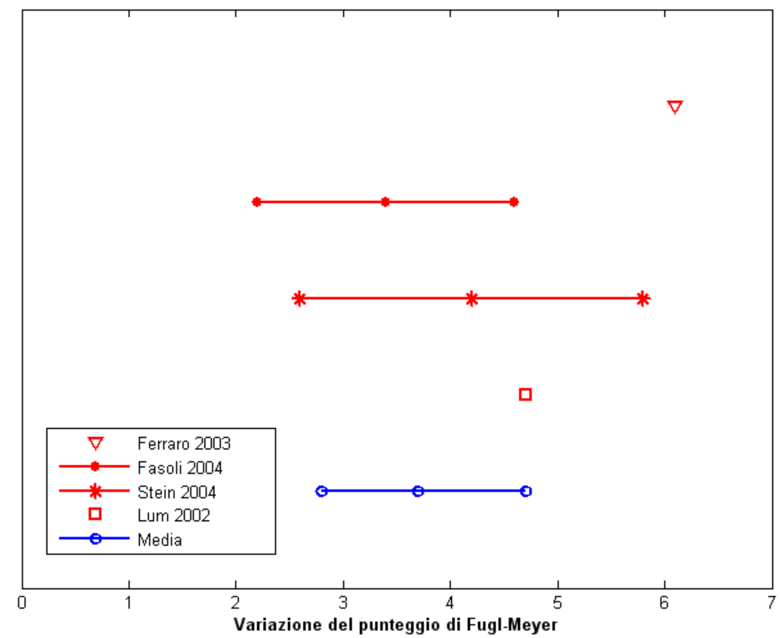


The Fugl-Meyer Assessment Scale

- The Fugl-Meyer Assessment (FMA) is a rating scale of impairment based on the performance of post-stroke patients. It was designed to assess motor functioning, balance, perception and the functioning of joints in hemiparetic patients. It is applied inthe clinical and research to determine the severity of the disease, describe the motor recovery and plan and evaluate treatment.
- The scale consists of five domains and there are 155 points as a total:
  - motor functioning (in the upper and lower extremities);
  - sensory function (light touch to evaluate the two surfaces of the arm and leg, and the perception of the position for 8 joints);
  - balance (contains 7 tests, 3 and 4 sitting in feet);
  - range mobilization of joints (8 joints);
  - joint pain.
- If reduced to the evaluation of the upper limb is only 66 points

A revision of current literature and main data

- Data from a review of 11 clinical studies of robotic assisted training: it shows how in all cases of intervention the robot assisted rehabilitation produces an improvement of motor function, evaluated with F-M scale:
  - F-M scale was developed as a first quantitative method for the assessment of the sensory-motor recovery
  - The increments are statistically significant, still not always relevant on the clinical side: current research is devoted to understand the most efficient strategy



Confidence Interval = 95%

- **However there are no differences in improvement of functional ability between the group undergoing robot-assisted therapy and the control group, while there is a short-term improvement in motor impairment, such as muscle activation and selectivity of movement.**

Prange, G.B., et al., ***Systematic review of the effect of robot-aided therapy on recovery of the hemiparetic arm after stroke.*** **J Rehabil Res Dev, 2006. 43(2): p. 171-84.**

Post-stroke timeline

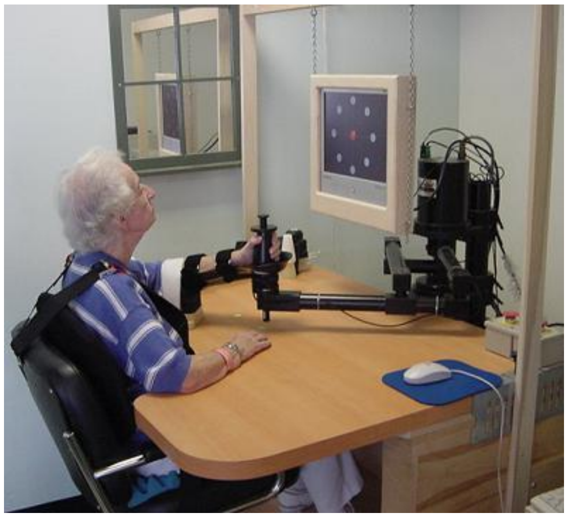
Acute — **1 month** — **Chronic (6 months – on, up to 5 yrs)**

- Loss of reflexes, Flaccidity
- Reflexes reappear, muscle tone increases
- Spasticity, Flexion synergy

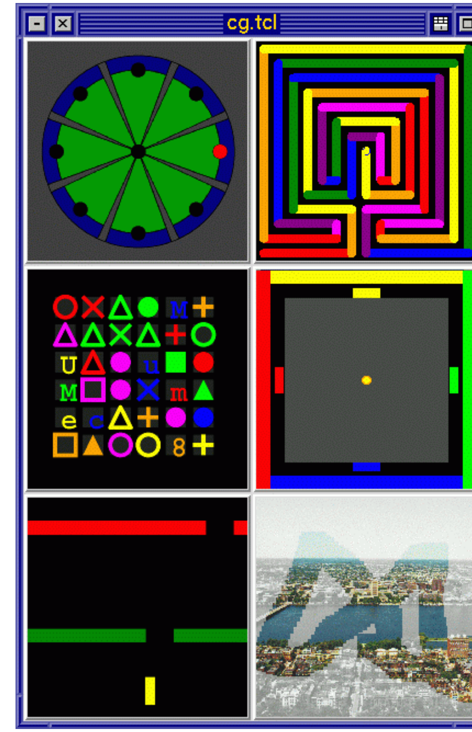
Stabilize or improve

MIT-MANUS

Evaluation with MIT Manus, Newman Laboratory for Biomechanics and Human Rehabilitation



- Robotic system with 2 degrees of freedom that allows movement plans of the shoulder, elbow and wrist
- The device can compensate for the weight of the patient's arm on the floor where the motion is carried.
- Low inertia and predominantly isotropic behavior (1 ± 0.3kg)
- Low friction and almost isotropic behavior (0.84 ± 0.2 8N)



Main limitations of the system

- Restriction of movements in the frontal plane: this excludes a large number of movement therapy.
- The device can not be used for functional rehabilitation
- Angular rotation between the screen display and the plane of movement

Acute phase intervention

Variation of indexes in the acute phase			
Group	Fugl-Meyer	Motor Status Score Shoulder and Elbow	Motor Status Score Wrist and fingers
Robotic therapy (40 pts)	**9,25±1,36**	**8,15±0,79**	**4,16±1,16**
Control (36 pts)	**7,1±1,20**	**3,42±0,62**	**2,74±0,78**

Krebs, H.I., et al., Increasing productivity and quality of care: Robot-aided neuro-rehabilitation. Journal of Rehabilitation Research and Development, 2000. 37(6): p. 639–652.

Chronic Phase Intervention

Evaluation	Start	End	Variation
Ashworth Modified	**12,76±5,23**	**12,08±5,70**	**-0,68±2,59**
Fugl-Meyer	**27,52±10,36**	**30,88±11,88**	**3,36±3,97**
Motor Status Score Shoulder/Elbow	**22,67±6,50**	**24,05±6,83**	**1,38±2,01**
Motor Status Score Wrist/Hand	**13,89±10,10**	**14,14±10,42**	**0,25±2,34**

S.E. Fasoli,H.I.Krebs, J.Stein, W.R. Frontera,R.Hughes, N.Hogan. Robotic Therapy for Chronic Motor Impairments After Stroke: Follow-Up Results. Arch Phys Med Rehabil Vol 85, July 2004

Fundamental issues in current rehabilitation practice

- For Upper Limb Rehabilitation, It is possible to see that 6 weeks of robotic training can lead to improvement of motor function
- Training is typically performed in standardized movement, such as
  - Single joint movement
  - Reaching movement in the plane
- **How can we assess the increase of ability of patient in ADL Activity of Daily Live?**
- **Do we reach enough improvements in real life (transfer of training)?**
  - **Wearing a jacket**
  - **Washing face**
  - **Eating, etc**

The typical scheme of usage of robotic training with asistance

- Reaching The task is often selected as the reference: it is a task critical for many daily activities
  - Typically takes place along straight lines
  - Velocity profiles are known in the execution of the movement (minimum jerk trajectory)

- Scheme of robot-assisted therapy
  - The patient receives feedback of the movement of the arm through its representation in the virtual environment
  - The movement begins when the patient is notified by a visual/acoustic signal or by the detection of given force threshold
  - The task is to pursue with the active movement of the arm a given target that moves with speed toward a pre-assigned target steady green ball
  - If the patient is not able to keep tracking the target object, the robot takes over applying an active force in the direction of the trajectory

The reaching movement, ballistic movement, human

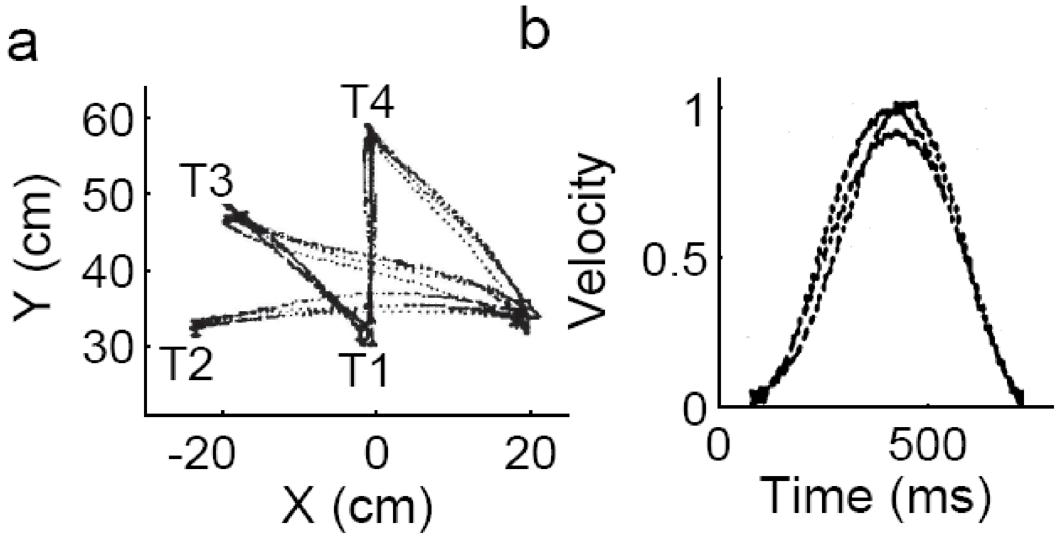


Figure 3. a) observed hand paths for a set of point-to-point movements from (Uno et al., 1989) (with permission). The coordinate system is centred on the shoulder with x and y in the transverse and sagittal directions respectively. b) observed velocity profiles for movements from T1 to T3 in a). Reprinted with permission from (Uno et al., 1989)

Minimum Jerk Trajectory

$$J = \int_0^T \left[\frac{d^3x}{dt^3}\right]^2 dt,$$

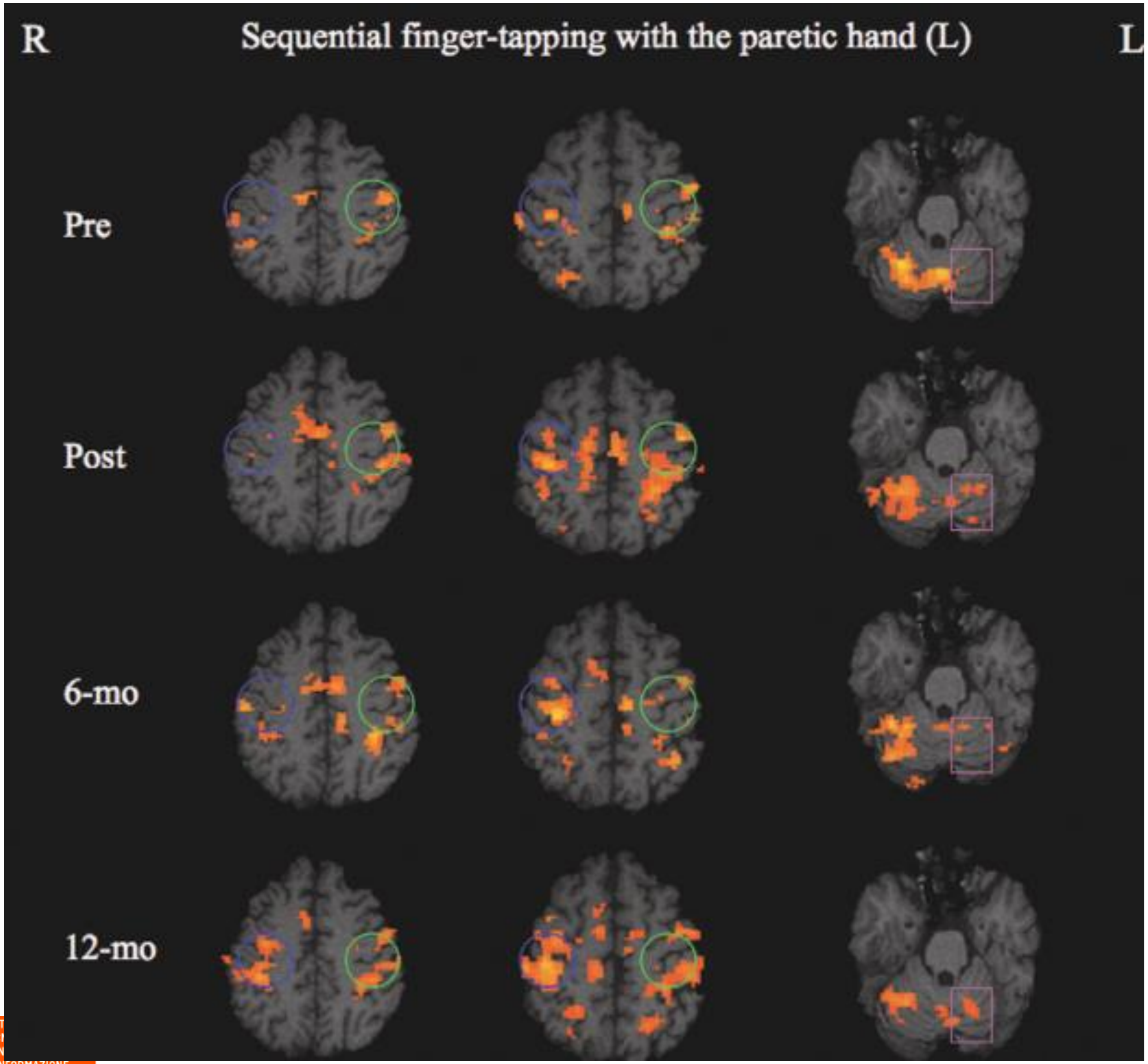
Minimum Torque Movement

$$J = \int_0^T \sum_{i=1}^{n} \left[\frac{d\tau_i}{dt}\right]^2 dt,$$

Effects of rehabilitation training (physical therapy)

- Stroke patients differ from control subjects for the motor cortical activation levels.
- Before treatment, the patients presents a reduced activation
in bilateral sensorimotor cortex,
with greater activation of ipsilateral (M1)
- After rehabilitation there is an increase in the levels of activation with a shift
to contralateral areas (ipsilesional)

Evolution of fMRI Activation in the Perilesional Primary Motor Cortex and Cerebellum With Rehabilitation Training-Related Motor Gains After Stroke: A Pilot Study, Neurorehab Neureal Repair (2007)



- Evolution of motor cortical and cerebellar activation patterns during sequential finger tapping with the paretic left hand in one patient.
- A progressive shift in M1 activation toward more contralateral (ipsilesional) involvement was observed across time (blue circle, ipsilesional; green circle, contralesional). The cerebellum was activated predominantly contralateral to the paretic hand movements for all 4 time points, but a continuous increase of ipsilateral cerebellar activation across time was observed (square).

Motor observation therapy

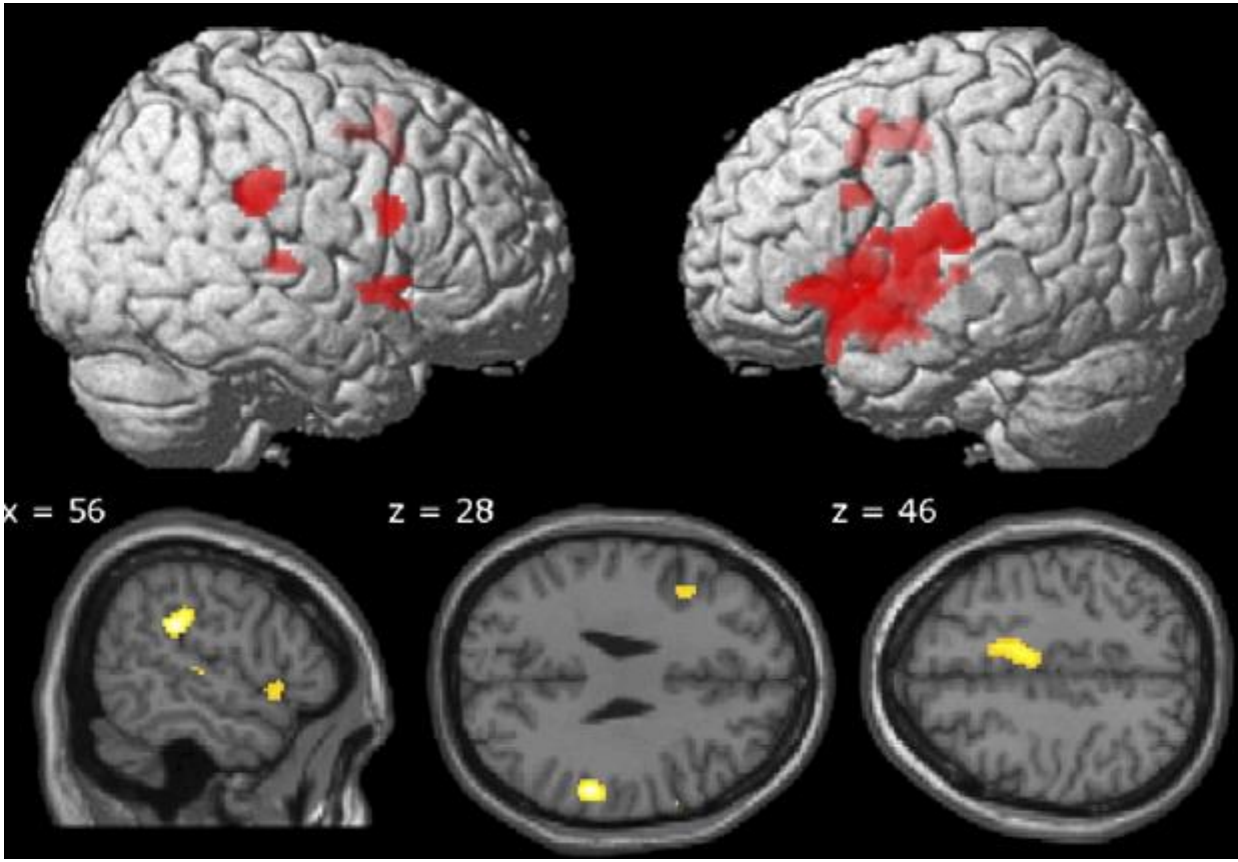
The principles of action observation therapy

- The observation of motor tasks in everyday actions combined with the concurrent exercise training, can lead to a significant improvement in motor function.
- There is evidence that in fact motor areas are recruited not only when the action is performed, but also when it is simply observed or mentally imagined (mirror neurons)
- Motor imagery has demonstrated to be useful in action sports training and rehabilitation

Ertelt et al., Action observation has a positive impact on rehabilitation of motor deficits after stroke, NeuroImage (2009)

Brain imaging and effects of action observation therapy in stroke

- As a result of the action-observation therapy treatment have a greater activation of:
  - Cortex ventral premotor (IFG)
  - Supplementary Motor Areas (SMA)
  - Supramarginal gyrus (SMG)
- This may indicate a reactivation of a network of physiological motor areas



Effect of training in virtual reality

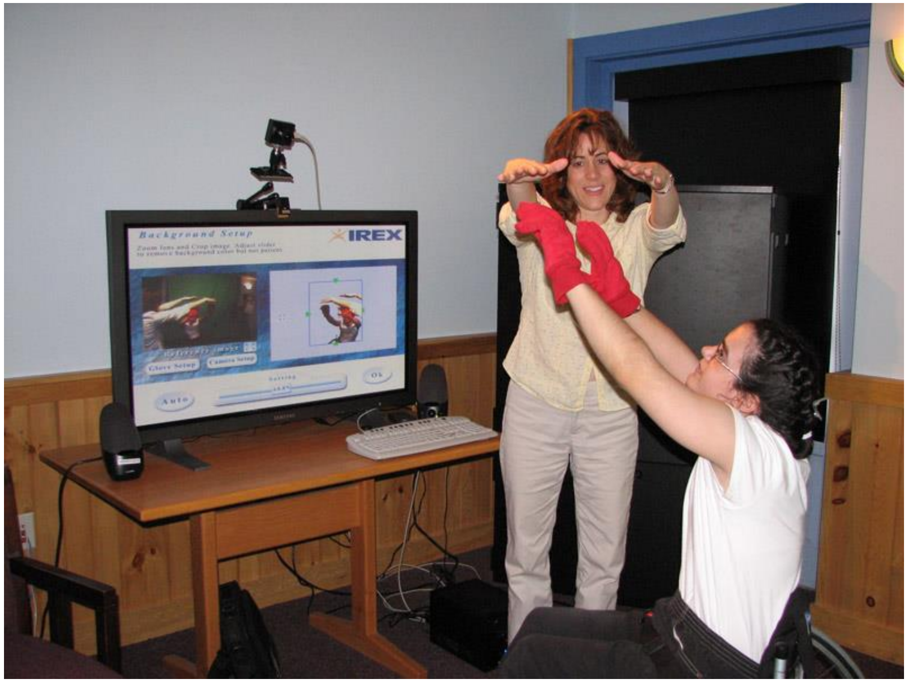
- Patients performed exercises in Virtual Reality associated to the task below + an augmentation of feedback given by
  - KR: knowledge of results, as an error (weight of objects)
  - KP: Knowledge of performance: quality of movement

Virtual Reality-Induced Cortical Reorganization and Associated Locomotor Recovery in Chronic Stroke: An Experimenter-Blind Randomized Study Stroke (2005)

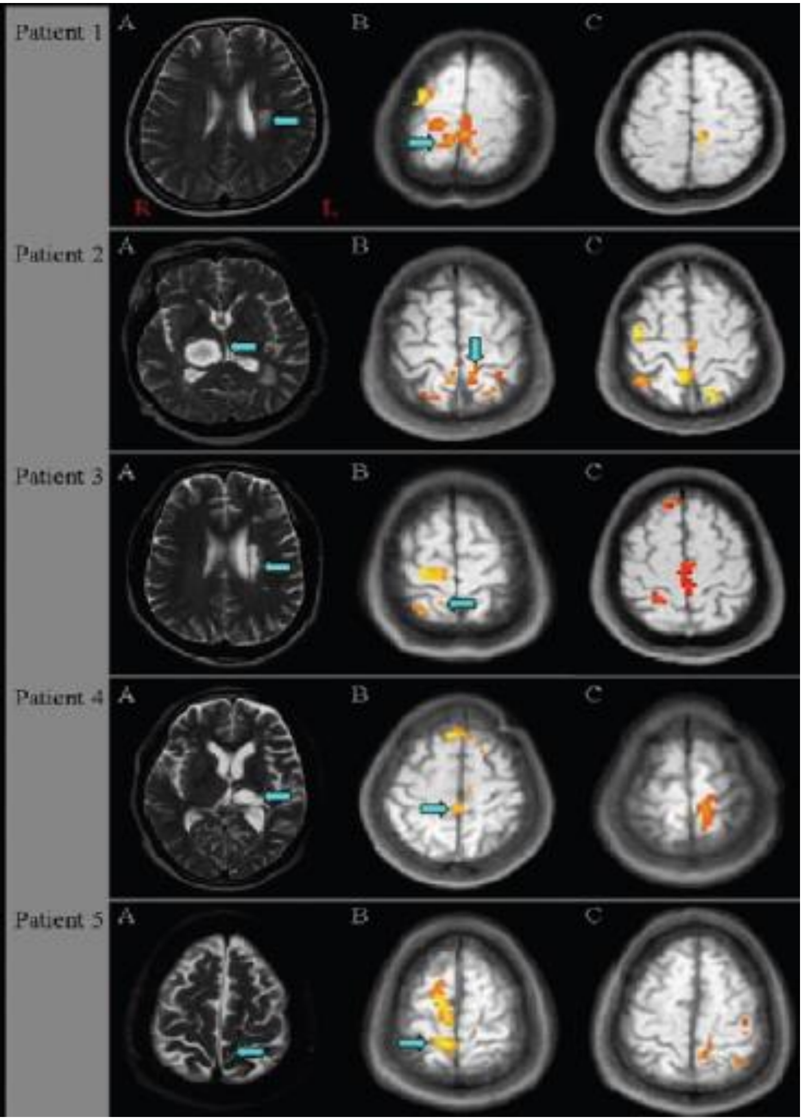
A. Stepping up/down B. Sharkbait C. Snowboarding

Used system

- I-rex system for motion tracking and impersonification into a virtual avatar



Effects of VR based training

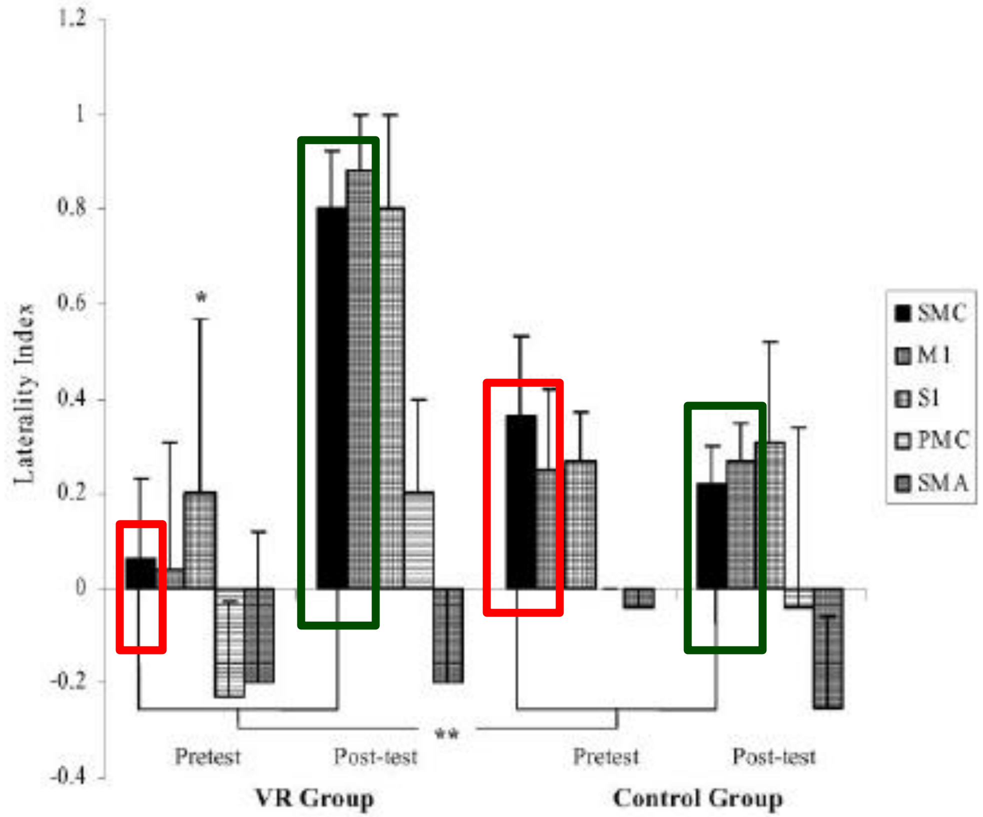


- Study conducted on 10 pts affected by stroke
  - A, T2-weighted diagnostic brain MRI images. The arrow indicates the lesion site.
  - B, Before VR, all patients showed the ipsilateral activations (arrow) at primary SMCs.
  - C, After VR, the ispilateral SMC activity (arrow) disappeared

Virtual Reality-Induced Cortical Reorganization and Associated Locomotor Recovery in Chronic Stroke: An Experimenter-Blind Randomized Study
Stroke (2010)

Increase of index of laterality

- Laterality Index (LI) measured at the level of Primary Sensorimotor Cortez SMC, associated to the knee movement



Virtual Reality-Induced Cortical Reorganization and Associated Locomotor Recovery in Chronic Stroke: An Experimenter-Blind Randomized Study

Stroke (2010)

Serious games and simulations

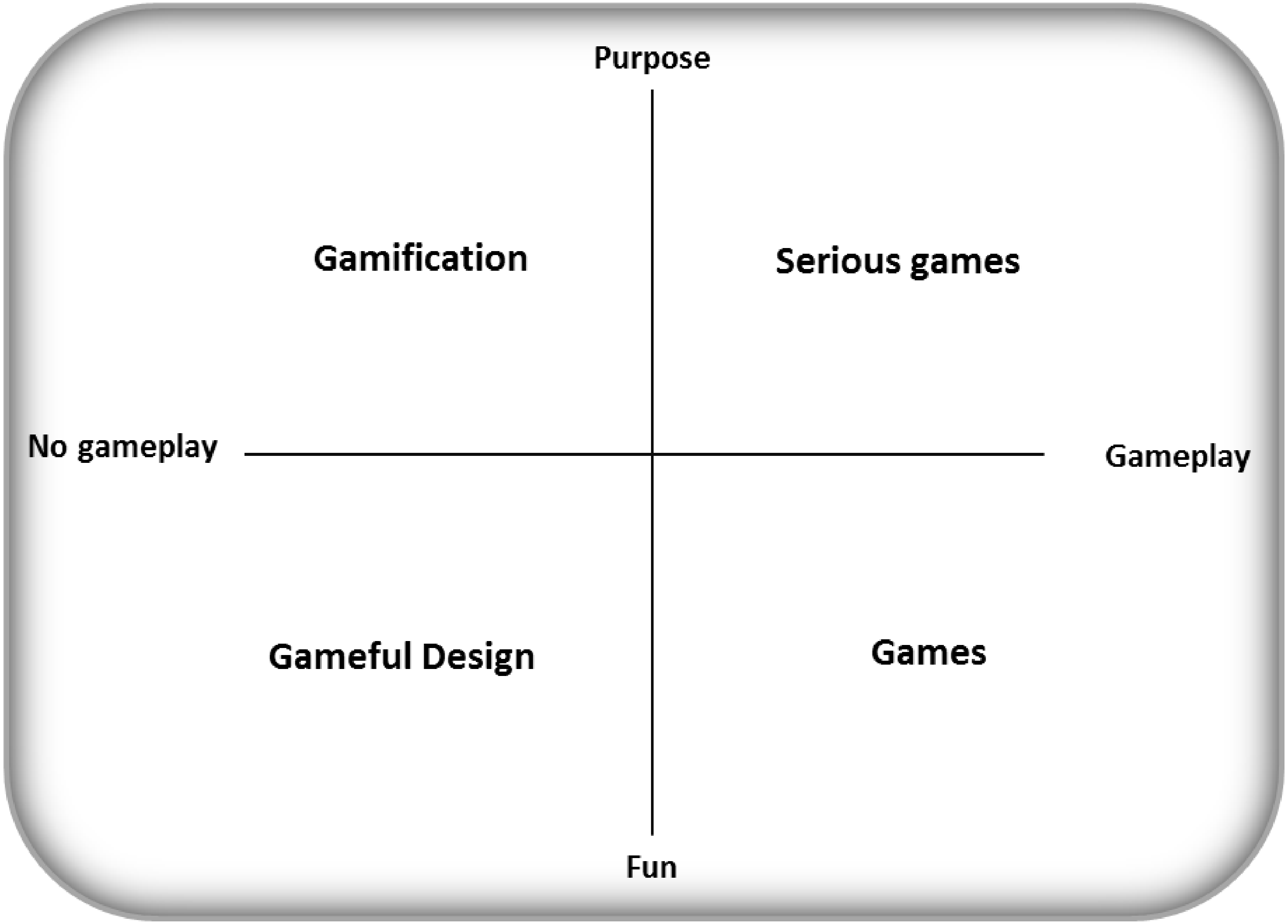
- The term “serious games” is becoming more and more popular
- A simple Google-search on “serious games” returns a percentage increase of about **300%** since 2007 until now
- There are many definitions and ways of classifying serious games and their *relationship to virtual worlds and simulations*
- **Games vs. Simulations**
  - **simulations** propose to represent reality
  - **games** do not
- In general, serious games are the accepted **term** for games with an **educational intent**.

Serious games

Learning through SGs

- In 450BC Confucius is reputed to have said: "*Tell Me and I Will Forget; Show Me and I May Remember; Involve Me and I Will Understand*".
- **Virtual Learning Environments facilitate on demand learning**, so what can be better than to give the learner portable learning materials
- From various research sources we know that we remember from:
  - the Lecture (5%)
  - Reading (10%)
  - Audio Visual (20%)
  - Demonstration (30%)
  - Discussion group (50%)
  - **Practice by doing (75%)**
  - Teaching others (90%)

Types of game thinking and primary design goal



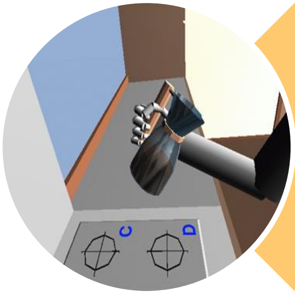
FATTORI NELL'APPRENDIMENTO

Occupational therapy

Occupational therapy intervention, such as activities of daily living,

Transfer is associated with perceptual similarities among tasks

Therapy in VR



Virtual reality offers the possibility to reproduce daily activities and tasks

Transfer leaning (in rehabilitation) refers to a person's ability to carry out the same task in a different environment.

Transfer is not at all-or-none phenomenon

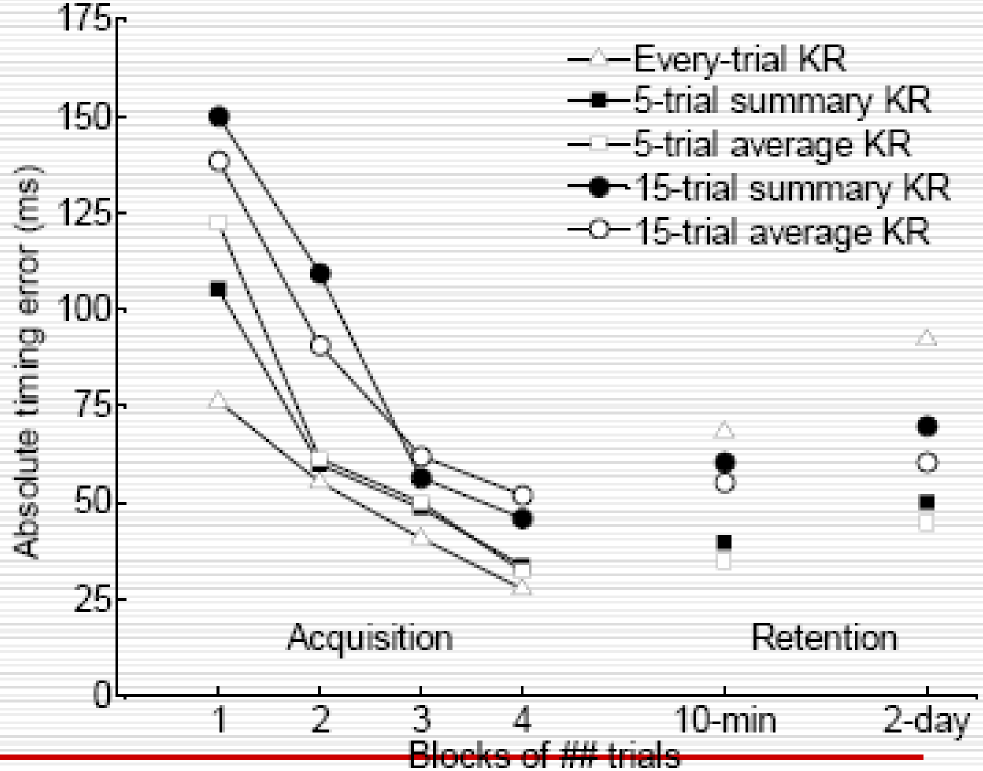
Near, intermediate, far, very far

Based on difference between learning and real-life environment

- Focus on reaching, fundamental movement involved in every ADL and associated to grasping
- Proposal of different exercises with equivalent activities in real-life: 3d puzzle, wiping

Knowledge of results – KR

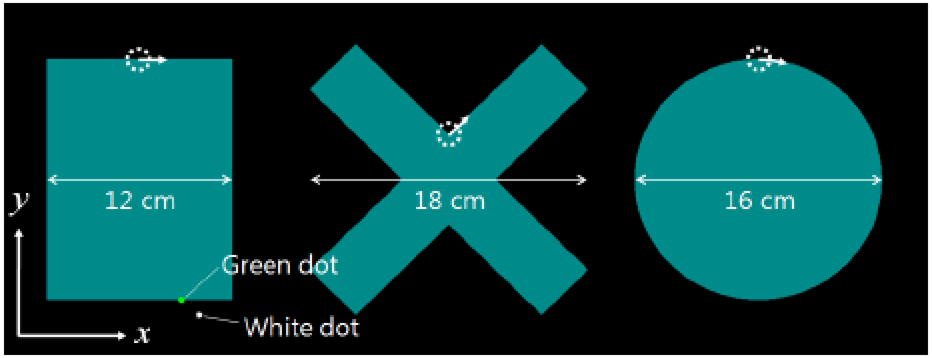
- Frequency of KR can impede or enhance learning depending on the task
  - High frequency KR acts similar to guidance in that subjects depend on feedback
  - Low frequency KR might delay the ability of the subject to make corrective actions.



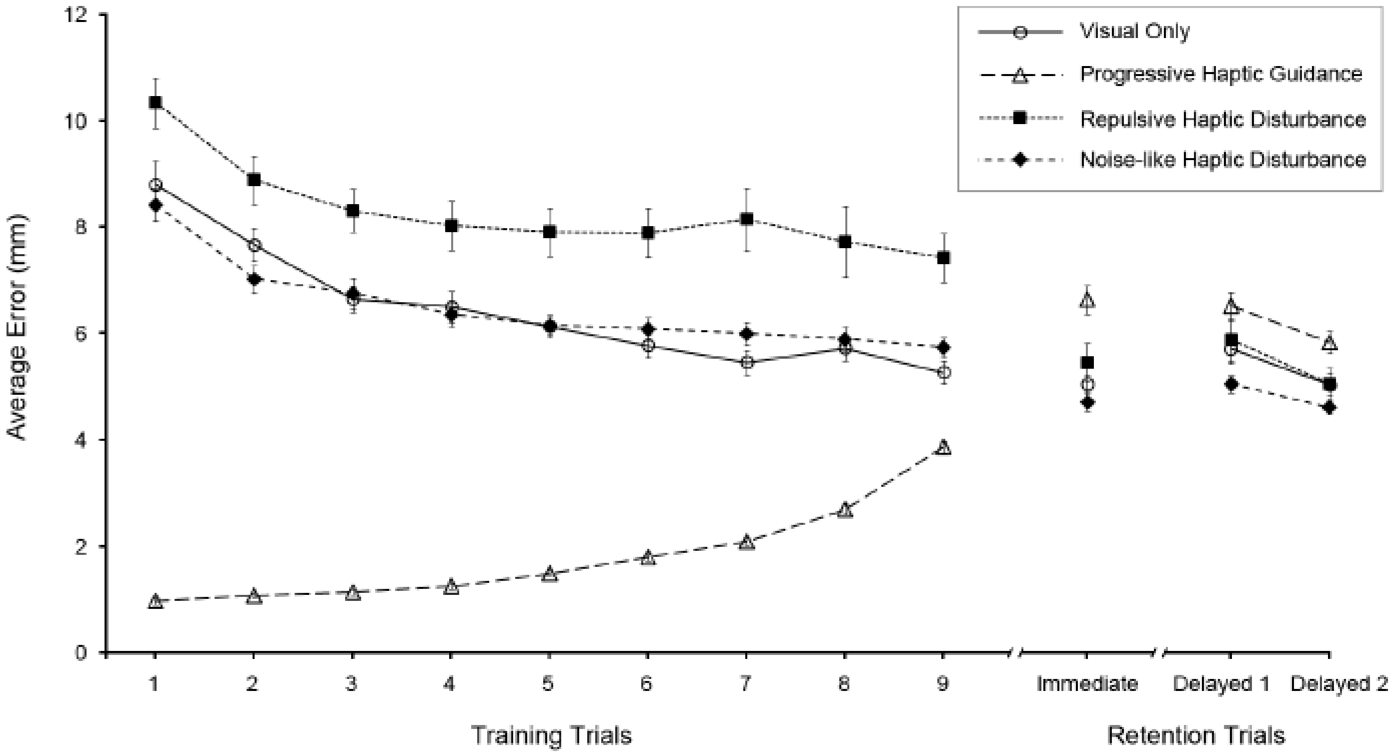
Yao, et. al. (1994)

Motor learning

- Example of different strategies used to provide augmentation in the learning process and reach a faster motor learning.
- Four training methods
  - visual only
  - progressive haptic guidance
  - haptic disturbance with repulsive force *(predictable disturbance)*
  - haptic disturbance with noise-like force (*unpredictable disturbance*).

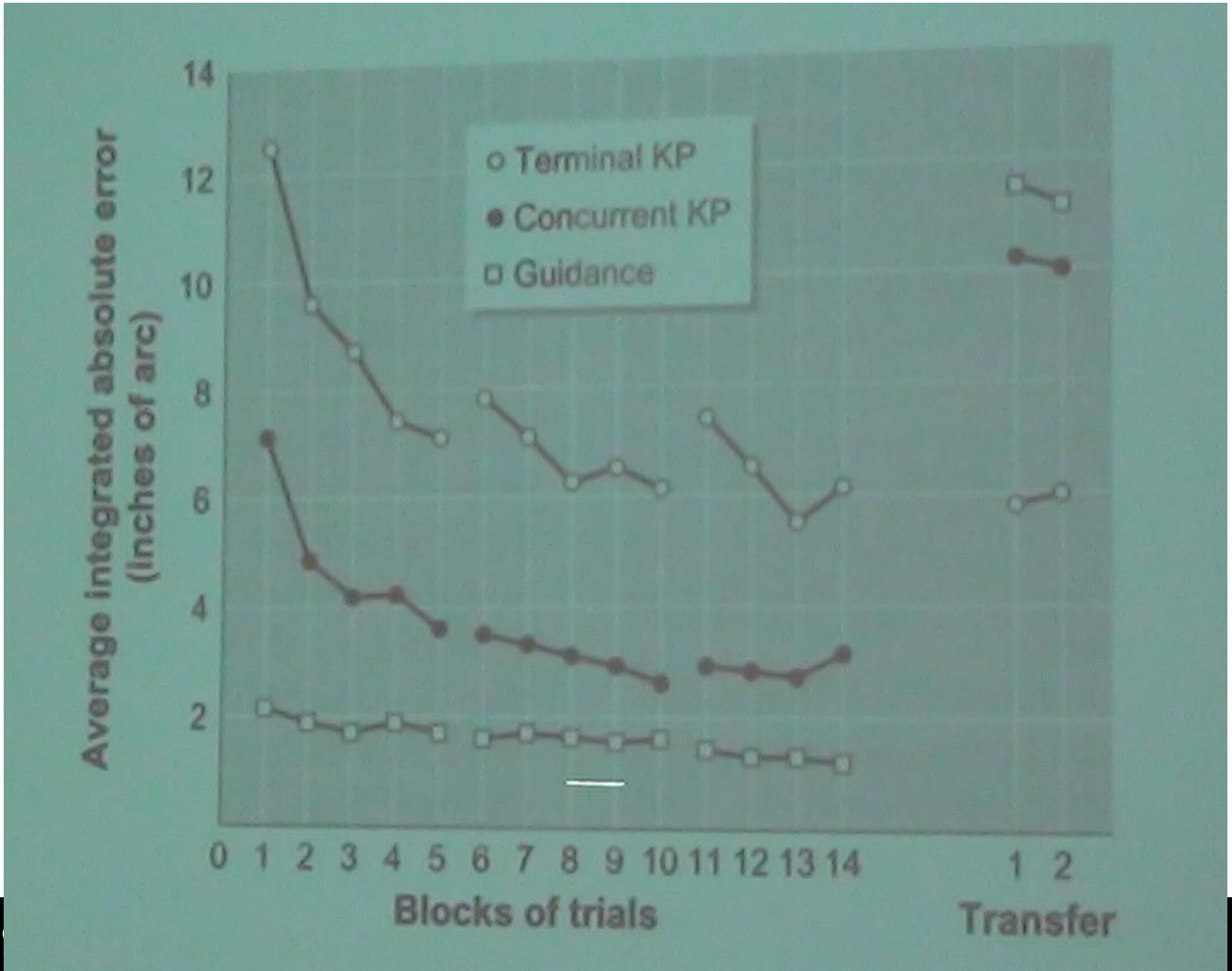


Retention of ability



Path guidance and transfer of learning

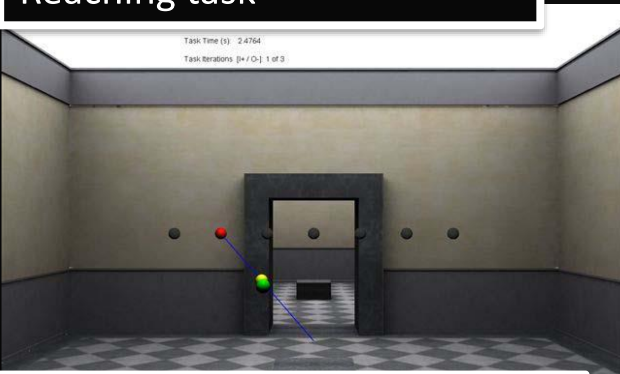
- First seminal study by Armstrong et al. (1970)



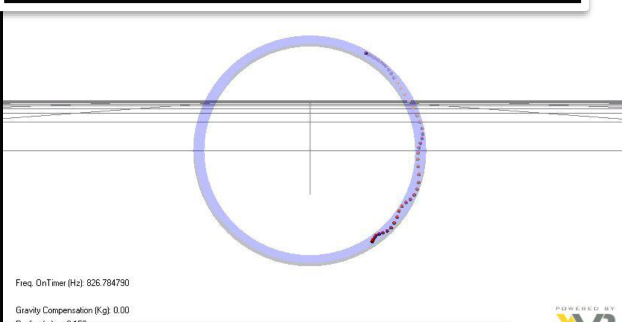
TEMPI DI APPRENDIMENTO

Proposed Exercises

Reaching task



Constrained movement task



Manipulation task

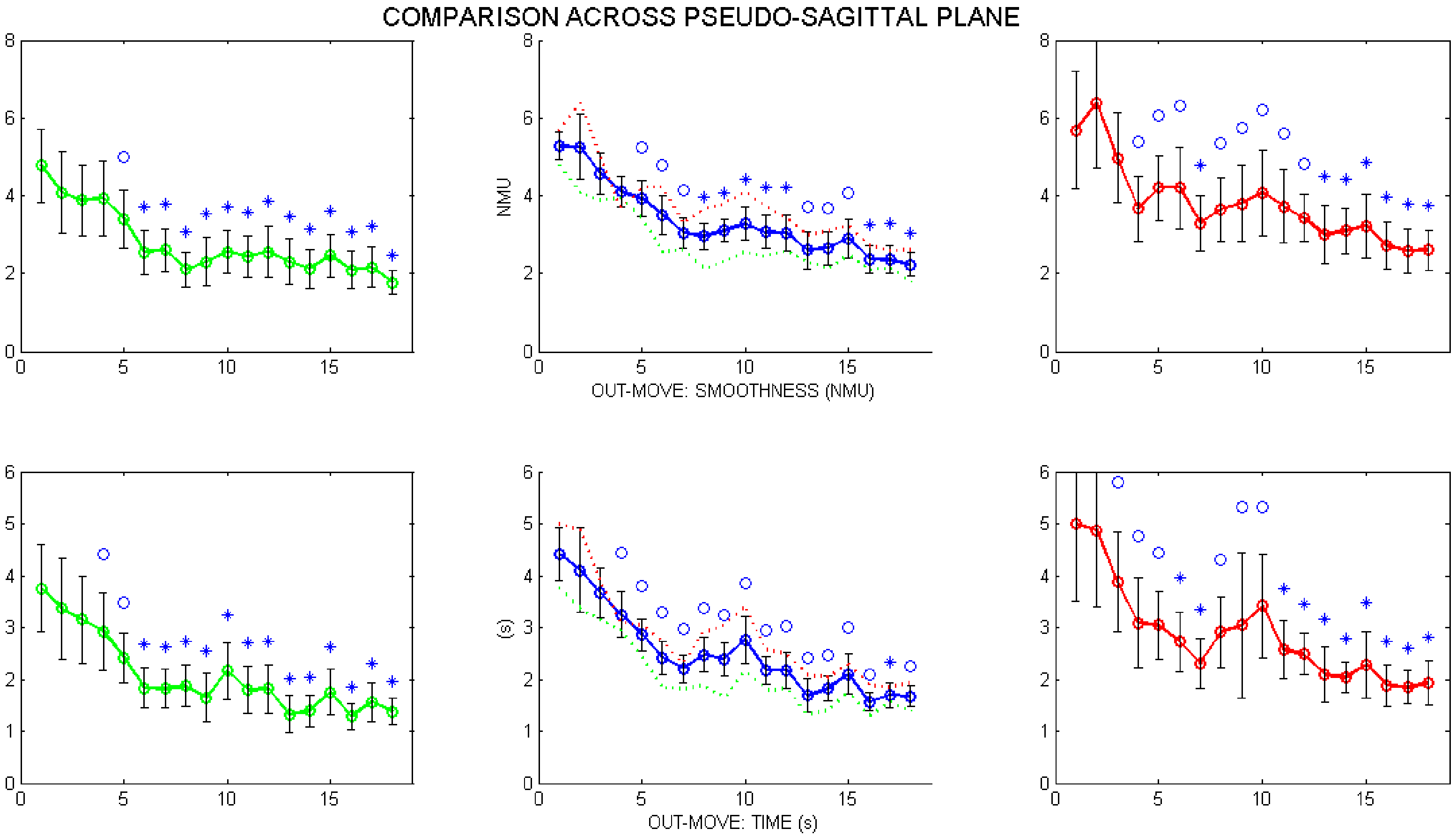
A Montagner, A Frisoli, Procopio C., B Rossi, et al. , A pilot clinical study on robotic assisted rehabilitation in VR with an arm exoskeleton device, Virtual Rehabilitation 2007, Venezia

Frisoli A., Procopio C. , Rossi B. et al. “Arm rehabilitation with a robotic exoskeleleton in Virtual Reality”, Proc. of IEEE ICORR 2007, Intern. Conf. on Rehabilitation Robotics

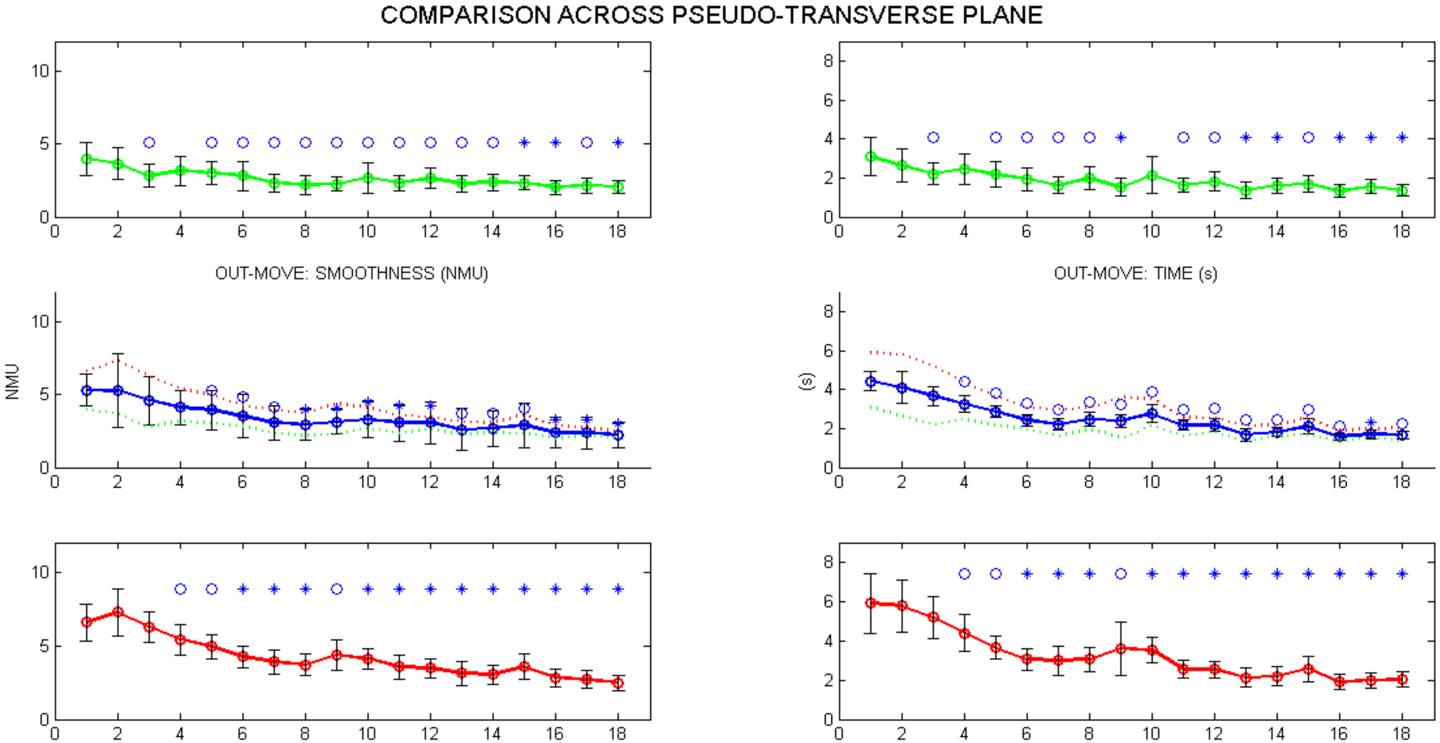
Exercise conducted with gravity support

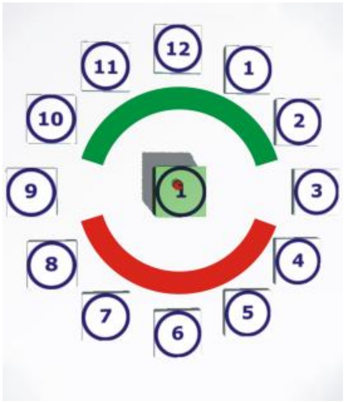
- Significant reduction in execution time of the trajectory
- Recovery of fluidity of movement
- Improving the execution time of the circle

Apprenidmento



Recupero motorio



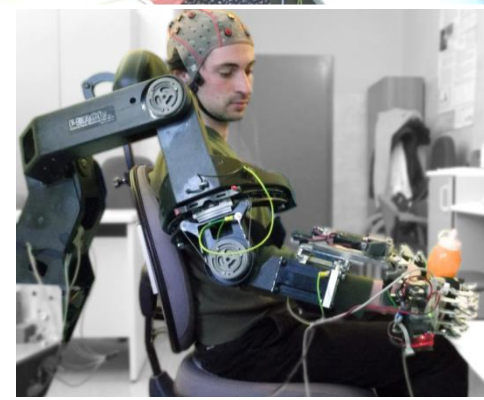


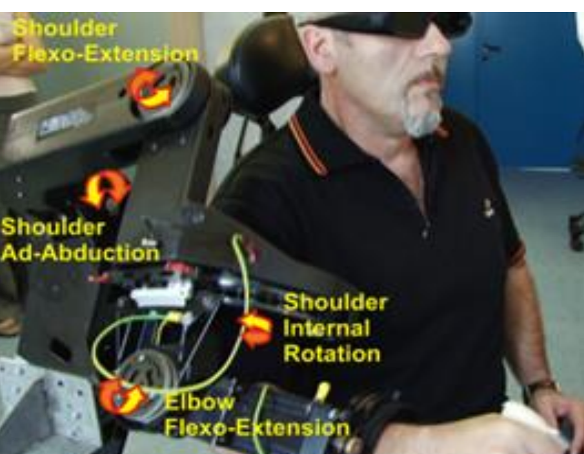
EXOSKELETONS AS A TOOL TO ASSESS MOTOR LEARNING

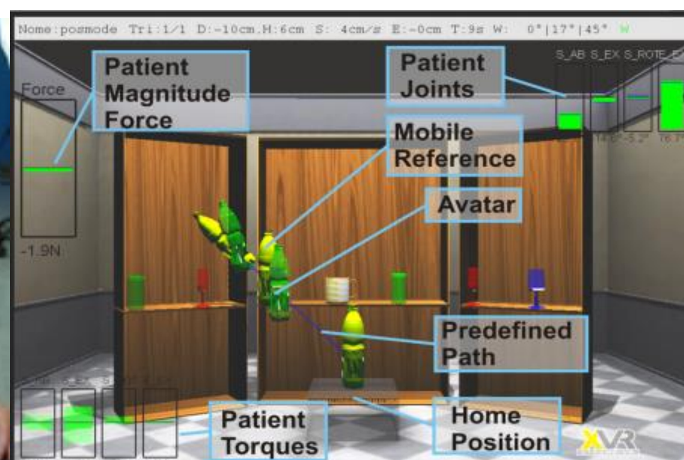
PERCRO Perceptual Robotics Laboratory

L-exos

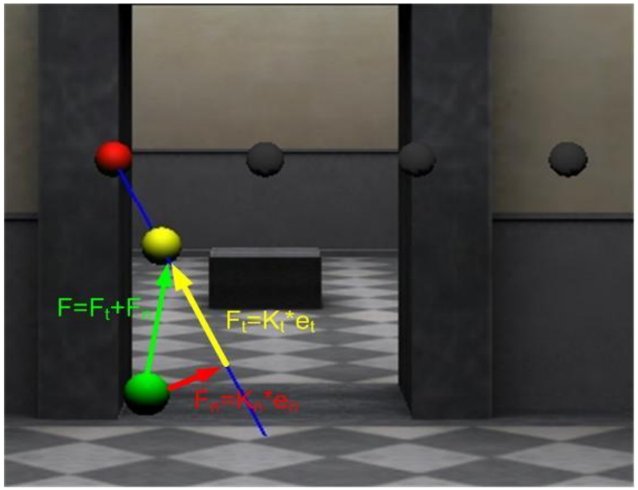
- 7 years of clinical evaluation of in stroke patients have shown its efficacy for upper limb rehabilitation:
  - Integration with hand exoskeleton for rehabilitation of grasp
  - EMG and BCI trigger for control of onset of assistance and guidance of movement

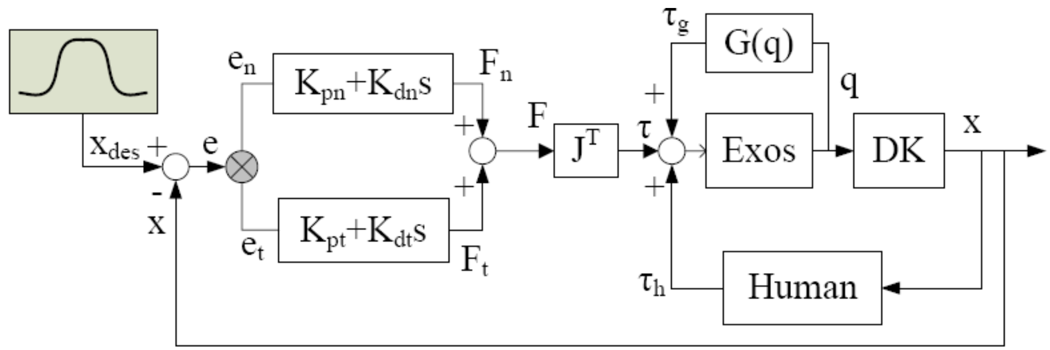






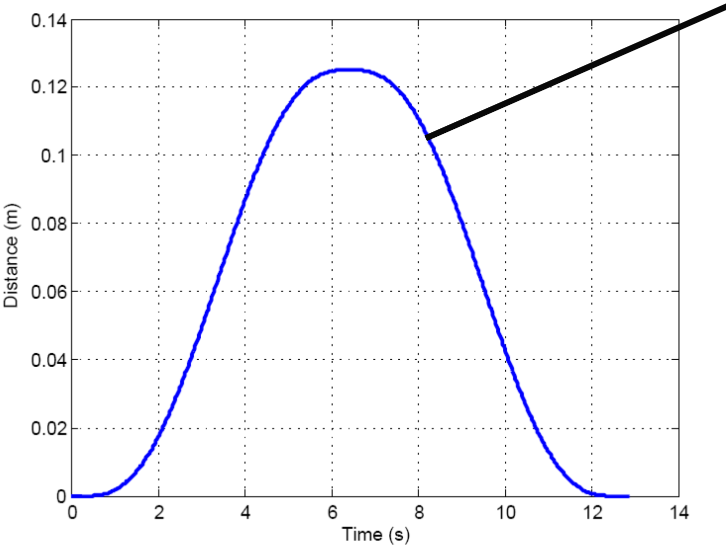
Assisted Teaching





$$\mathbf{e} = \mathbf{x}_{des} - \mathbf{x}$$

$$\mathbf{e} = \mathbf{e}_n + \mathbf{e}_t$$



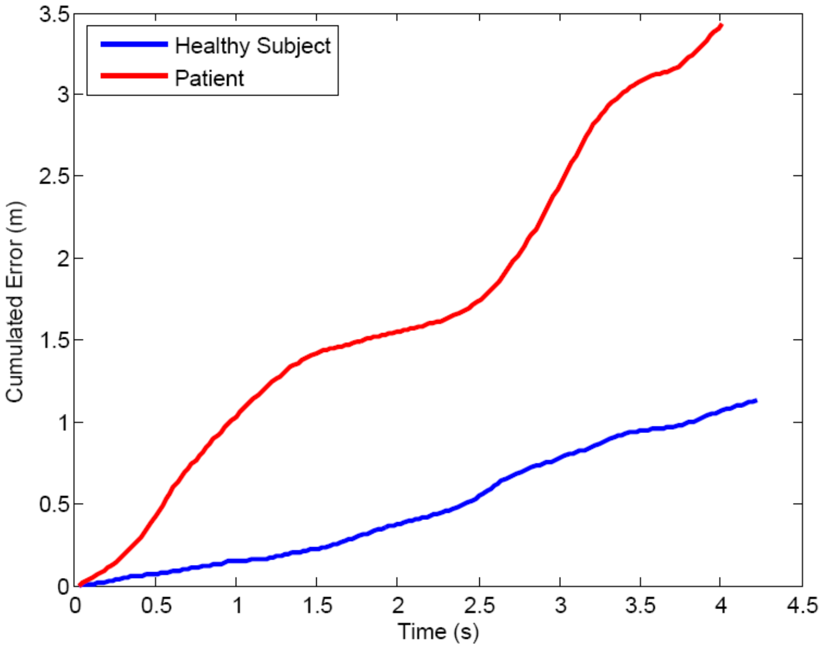
hogonal **impedance controllers** are
rst being along the direction of the
t), the second laying on the plane
tory (Kn)

$$\mathbf{F} = \mathbf{F}_n + \mathbf{F}_t = (K_{pn} + sK_{dn})\mathbf{e}_n + (K_{pt} + sK_{dt})\mathbf{e}_t$$

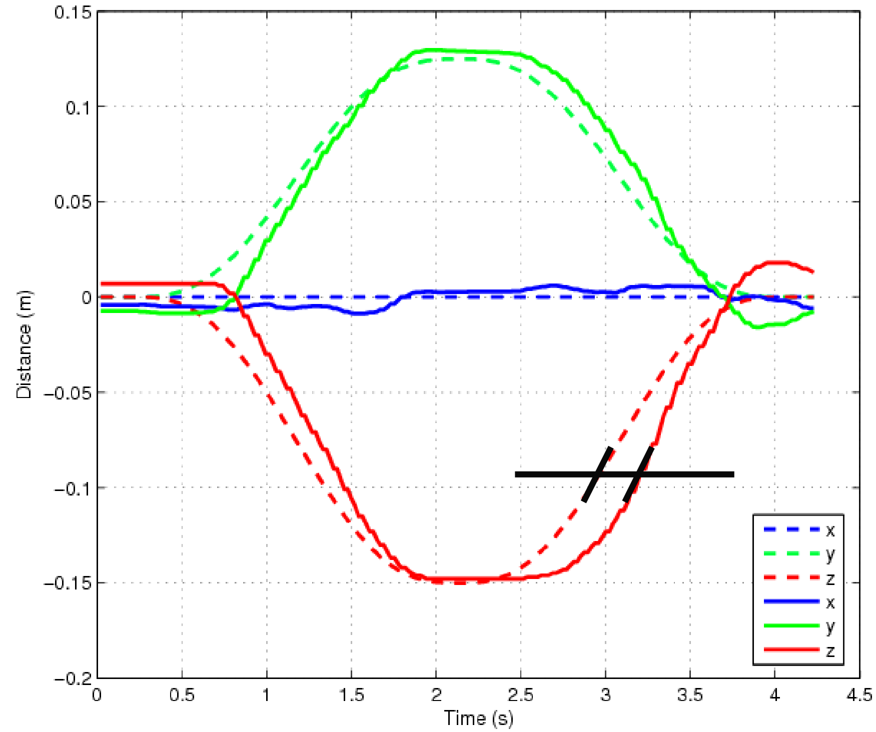
: in order to display a sort of **haptic**
tient is relatively free to move
› both forces in order to increase

$$\boldsymbol{\tau} = G(\mathbf{q}) + J^T(\mathbf{q})\mathbf{F} + \boldsymbol{\tau}_h$$

Performance comparison in reaching



Task in the frontal plane



Patient performance

Healthy subject vs. patient performance in the reaching scheme

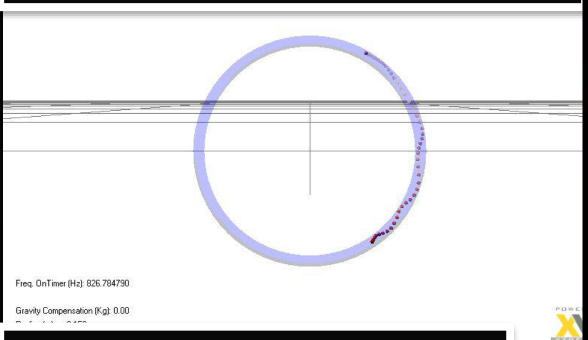
The robot anticipates the patient's movement

Frisoli et al. Applied Bionics and Biomechanics (2010)

Chronic stroke rehabilitation with the L-Exos

Reaching task

Constrained movement task



Manipulation task

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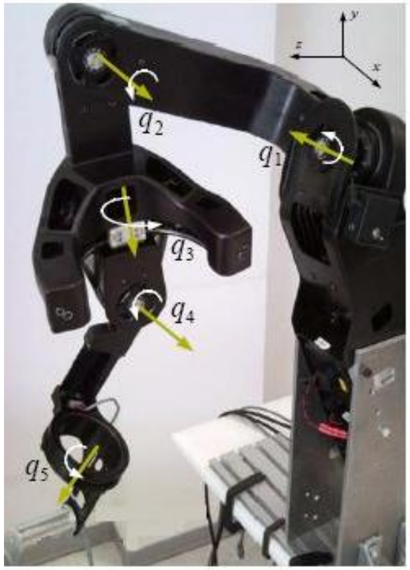
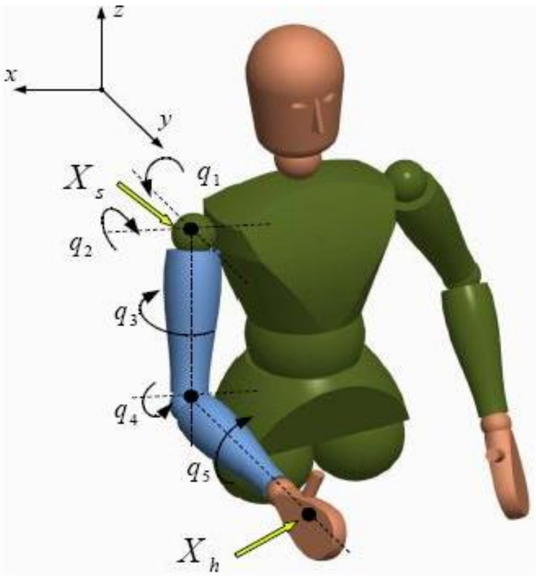
Frisoli A., Procopio C. , Rossi B. et al. “Arm rehabilitation with a robotic exoskeleleton in Virtual Reality”, Proc. of IEEE ICORR 2007, Intern. Conf. on Rehabilitation Robotics

Alex: the upper limb exoskeleton

L-Exos device: performance summary

Continuous force	50 N
Peak force	100 N
Total weight	11 kg
Weight of moving part	5 kg
Backlash at the End Effector (worst case)	10 mm
Stiffness at the End Effector (worst case)	2 N/mm
Reduction of human	





Weight / payload ratio of almost 1:

<u>100 N vs. 11 Kg</u>

Participants

- 18 chronic stroke patients were selected at the Neurorehabilitation department of AOUP hospital in Pisa.
- They were enrolled in two groups with random assignment to the experimental or the control group .

The experimental group was administered robotic therapy by means a robotic exoskeleton

ROBOT

The control group was assigned to physical manual therapy.

CONTROL

Methods

- The experimental and conventional physical therapy treatments were matched in terms of intensity, duration and tasks.
- Patients performed 3 weekly sessions of rehabilitation over a period of 6 weeks, with evaluation at the enrollment and discharge.
- Clinical assessment
  - FMA Fugl-Meyer Assessment Scale
  - Bimanual Activity Scale(BAT)
  - Ashworth scale
  - Robotic evaluation

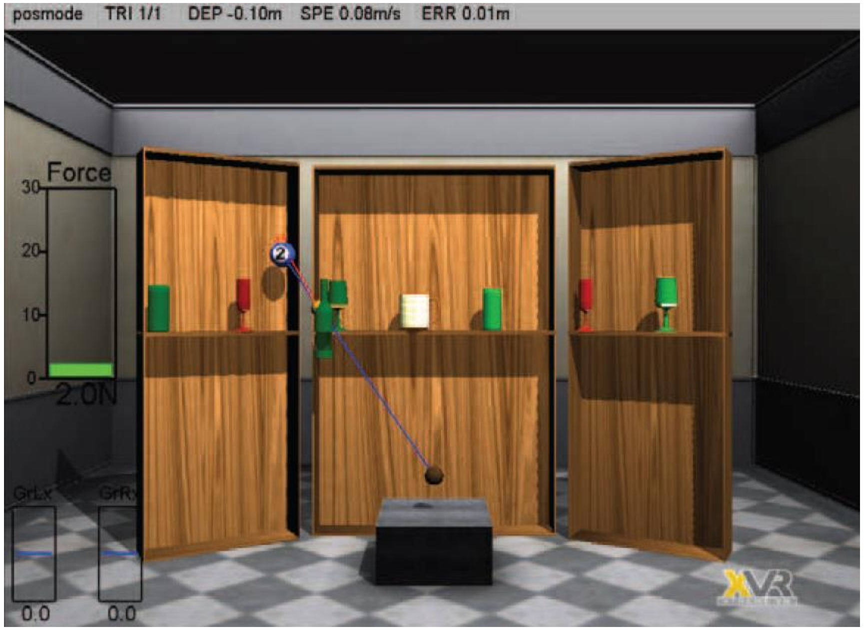
The training

The reaching task

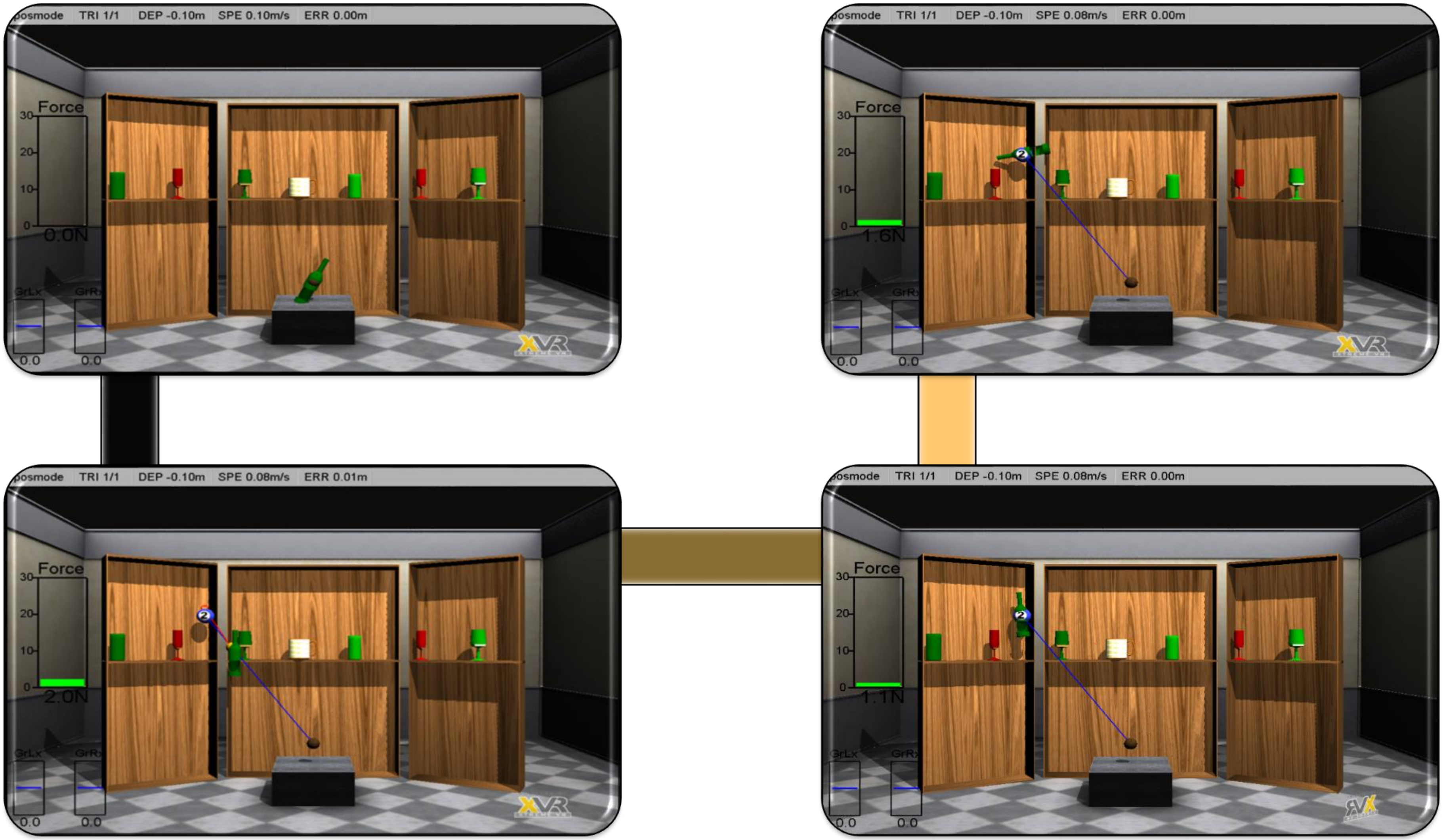
- Objectives
  - The goal of this task begins when the therapist chooses the desired object to be reached and the Light-Exoskeleton leads the patient right-arm from the point O to the desired target.

- Treatment session:
  - the exerted force at the handpalm of the patient is registered during the reaching task and used to modulate the helping contribution of the device to perform the required task. When the patient is on the target the hand prono/supination allows the yellow ball to start the inward movement to the starting position.

- **Evaluation session:**
  - the patient is asked to move the arm to reach the final target with a given velocity, minimizing the position error with the yellow marker that moves automatically toward the target. The contribution of L-Exos regards only the aid to stay inside the straight line.



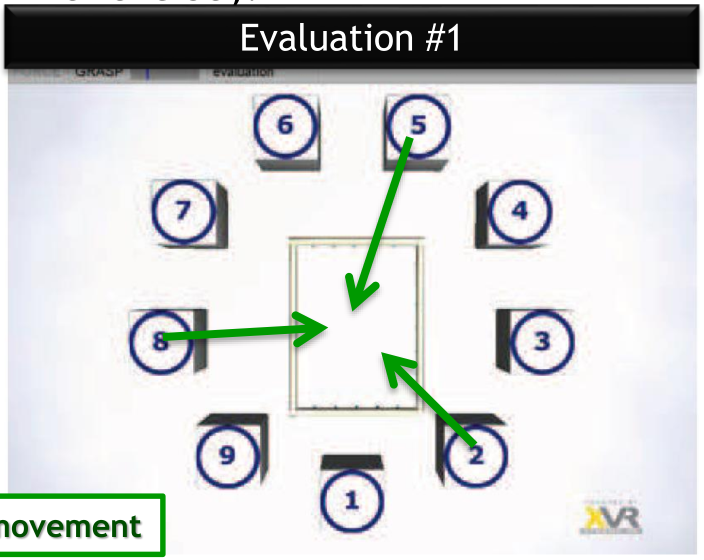
The reaching scenario with different strategies implemented



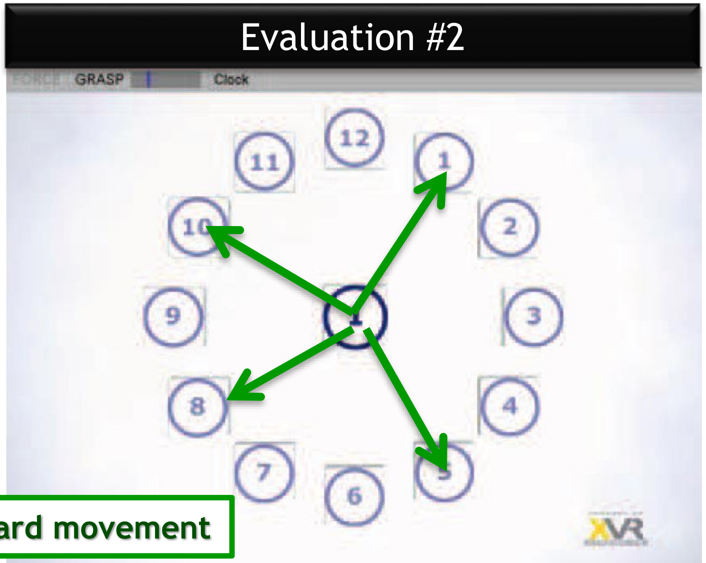
The cubes game

- Treatment session
  - in a 3D virtual environment the patient is asked to redo the puzzle shown in the central position; the cubes are randomly placed around the picture. The game is over when the patient finishes the whole puzzle.

- Evaluation session
  - in the same environment the patient is asked to perform two similar task in which he/she has to move sequentially the cubes, from the periphery to the center (Basket exercise) and vice versa (Clock exercise).

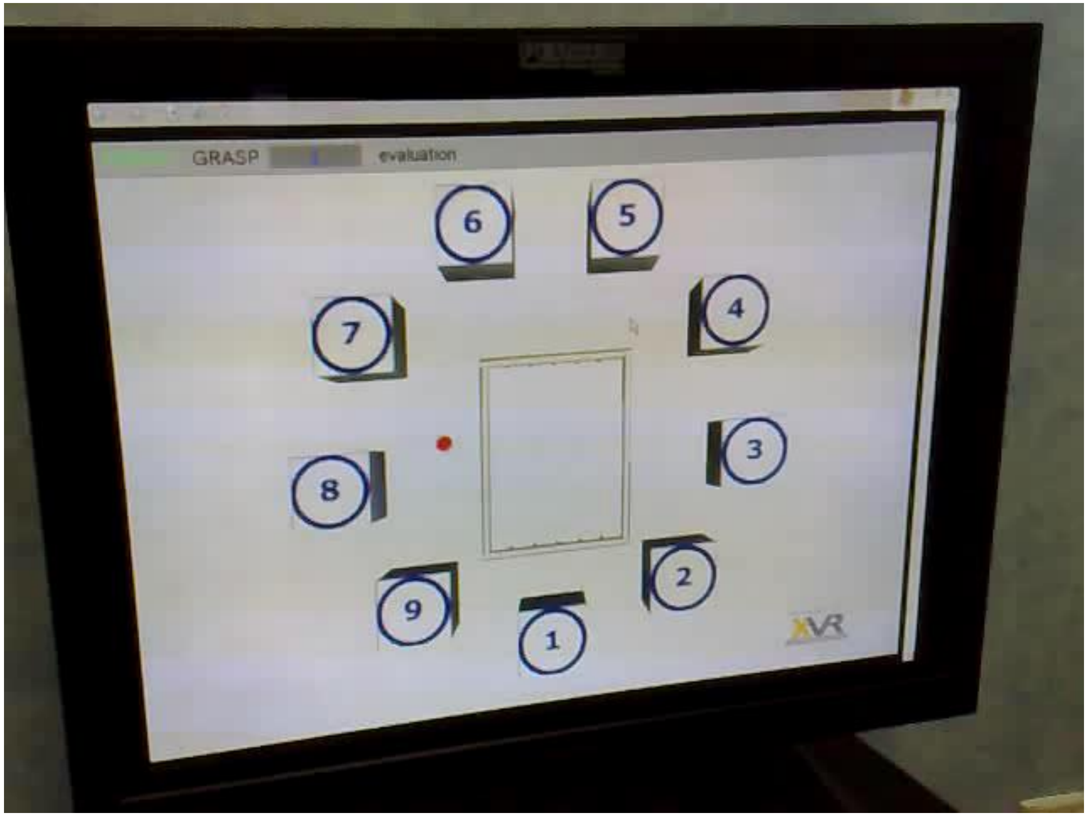


Inward movement



Outward movement

The evaluation scenario



Evaluation

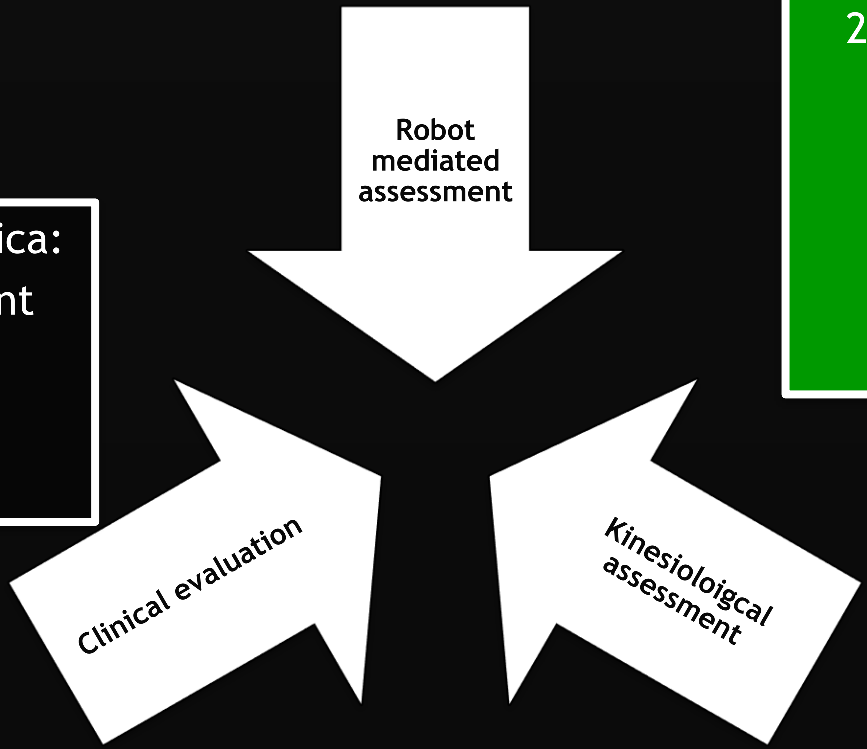
3 scale di valutazione clinica:

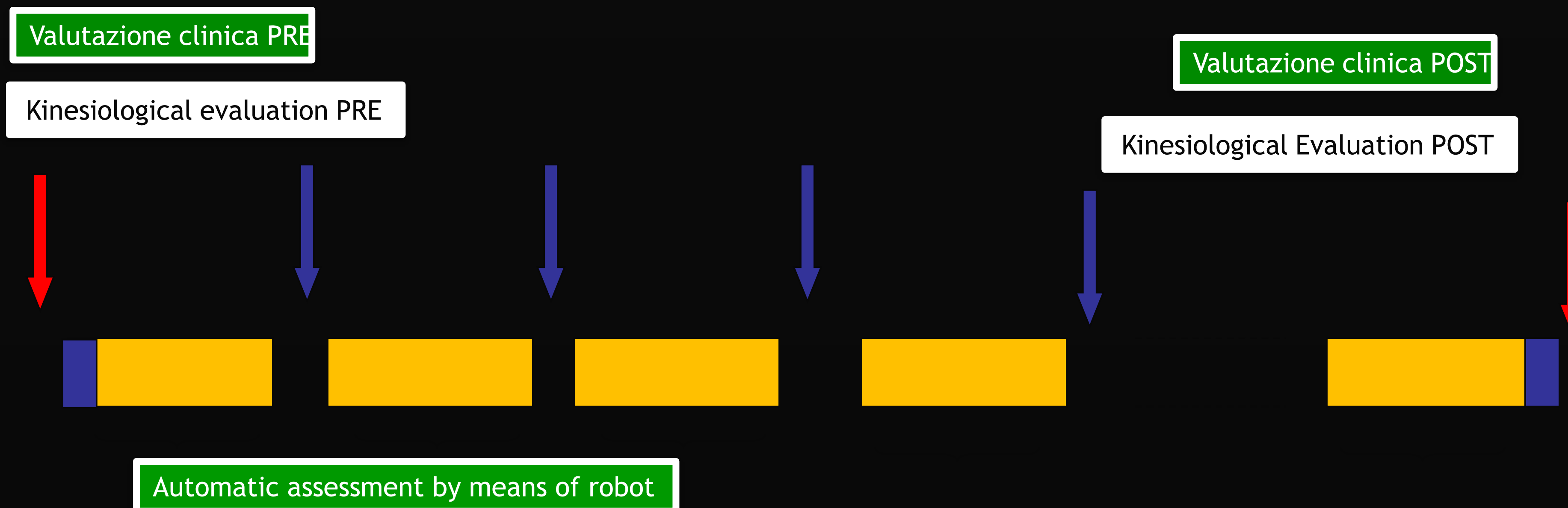
1. Fugl Meyer Assement
2. Ashworth Scale
3. Range of Motion

2 tasks with robot assistance:

1) Active guidance in reaching

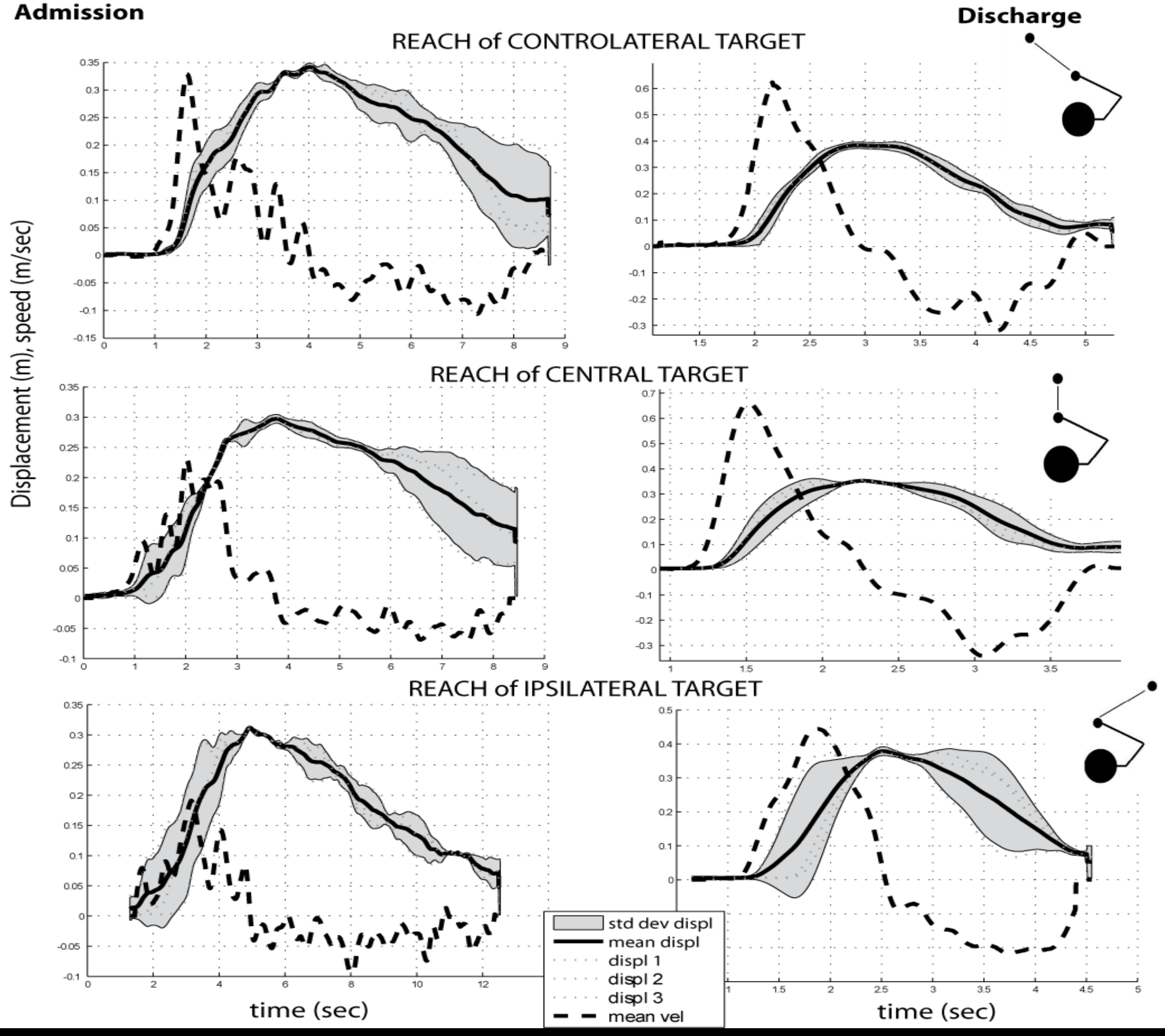
2) constrained motion in circular trajecotries

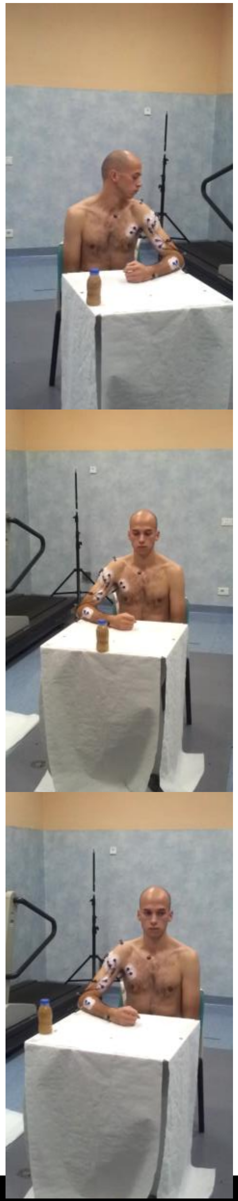




PARAMETRI CHE POSSONO ESSERE USATI NELLA STIMA DEL RECUPERO NEUROMOTORIO

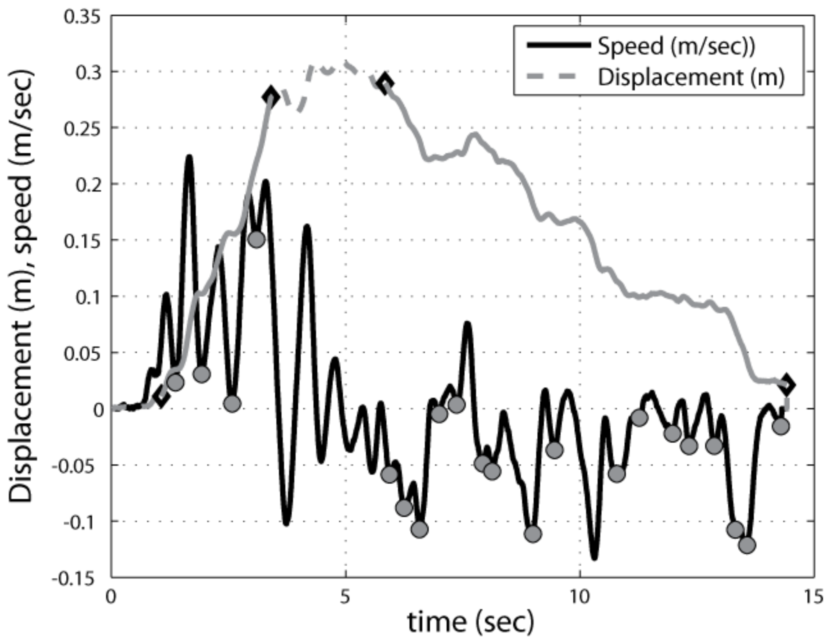
Effect of robotic assisted rehabilitation





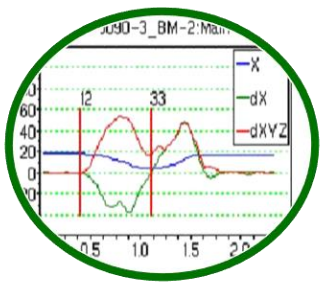
Performance indexes that correlates with increased performance

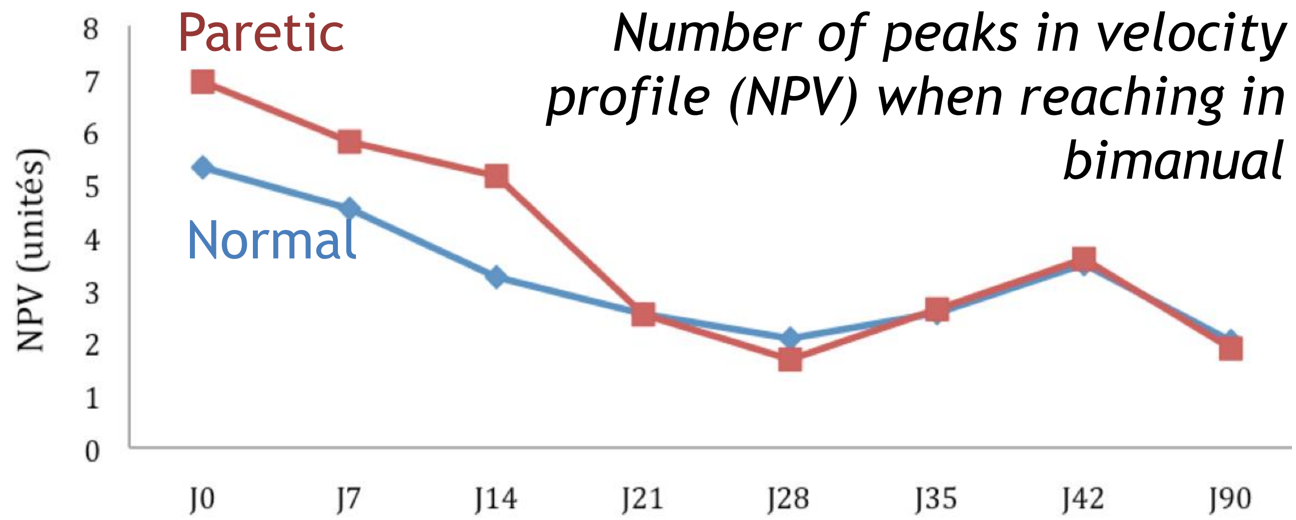
- Time execution: this can be automatically extracted from recorded motion and it is a measure of efficiency of movement execution (PI1)
- Count of minima in the velocity profile: index of smoothness (PI2)



What patients for the bimanual therapy ?

- Deficit in kinematic organization

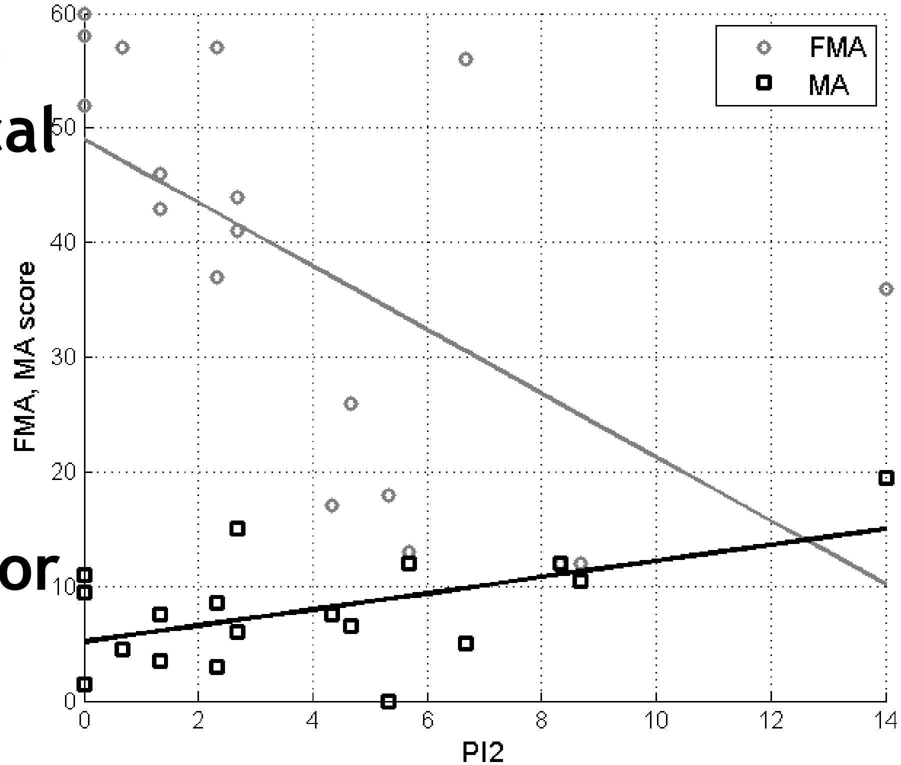




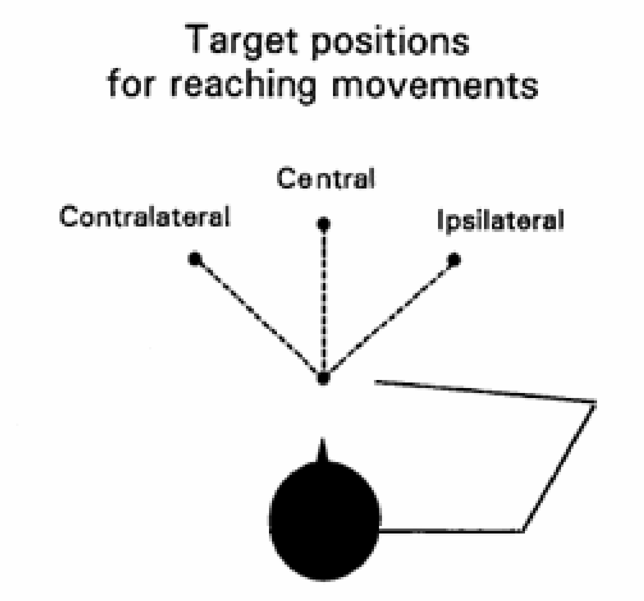
- Conclusion
  - It seems important to train bimanual early

Correlations

- These data correlates well **with clinical assessment**
- So performance time and number of velocity peaks are **predictors of FMA and clinical status of patient**
  - **We can use performance parameter to study motor function under different conditions**
- Does this mean a **better motor control→ improved motor function??**

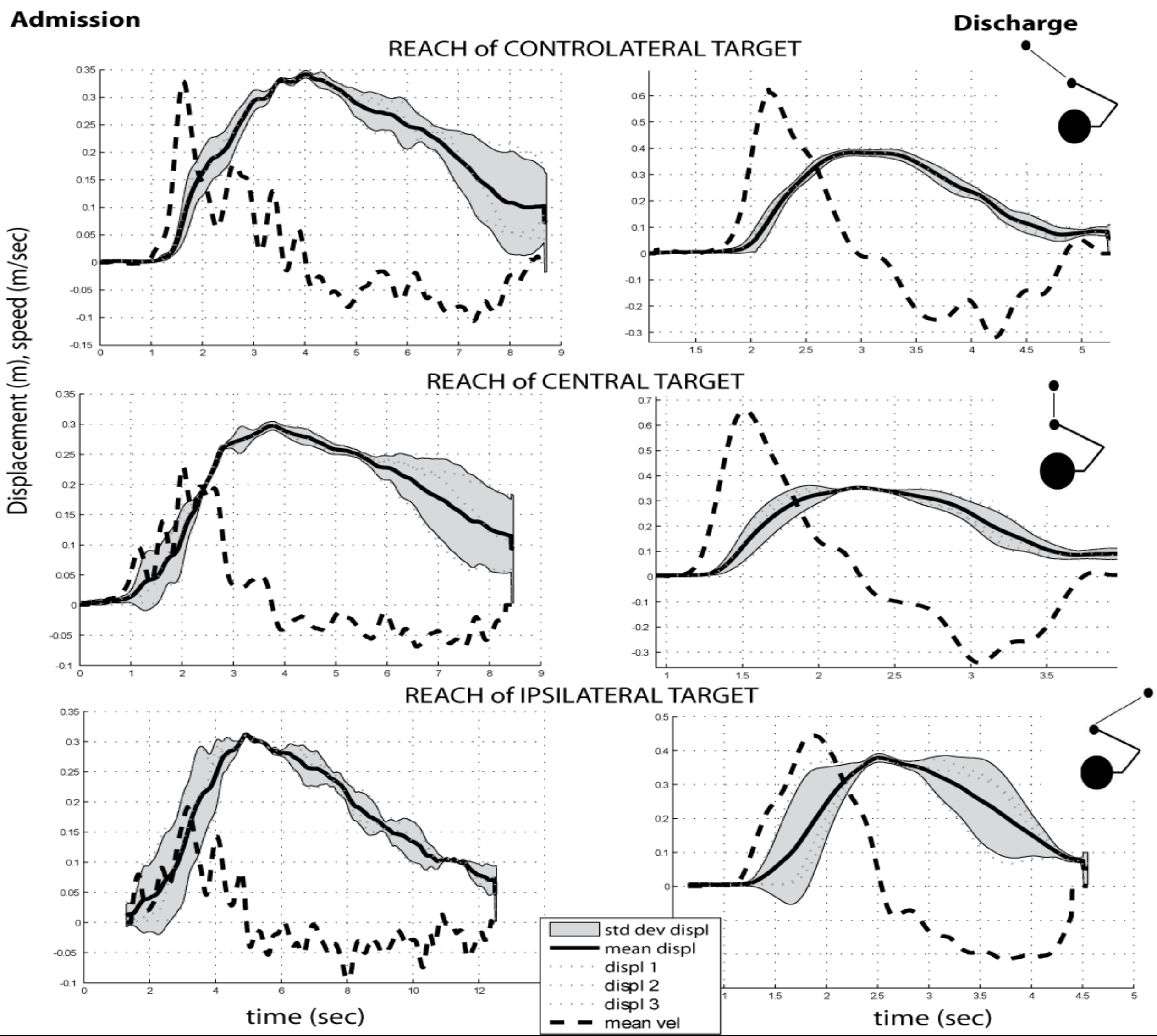


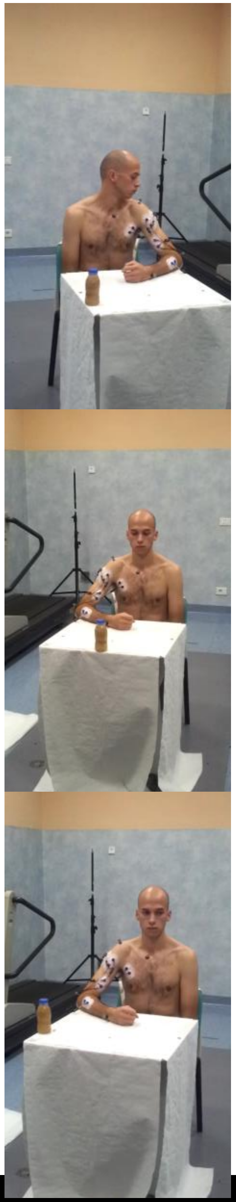
Kinematic data acquistion and analysis



- Kinematic and electromyographic recordings were obtained when the subject performed three different tasks if reaching.
- The motion tracking system that has been used in BTS Elite 8-channels for EMG and 6 channels dedicated to the cameras for the kinematic analysis of movements.
- The motor task was repeated 18 times at different speeds and to achieve target 3 different positions: the patient is asked, for each position, repeating the movimento3 times normal speed and 3 times at maximum speed.

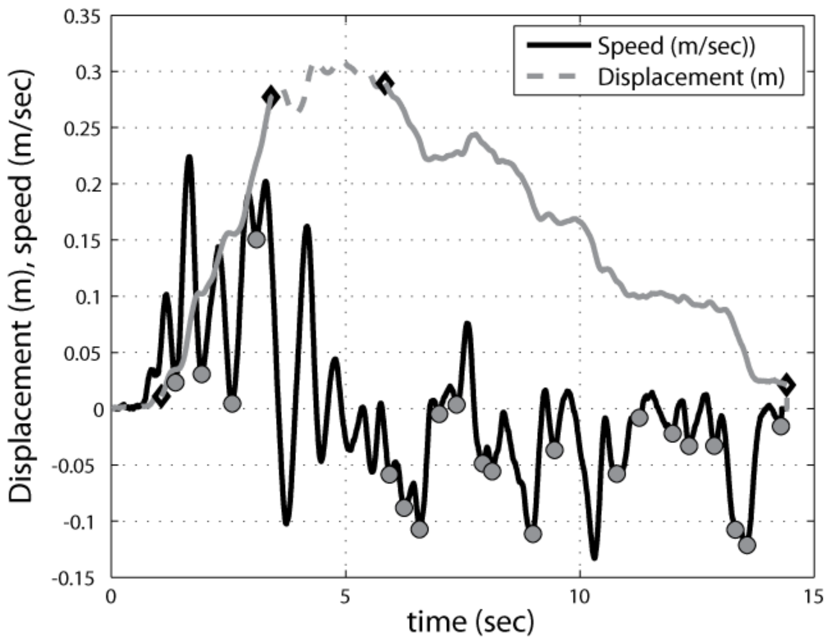
Effect of robotic assisted rehabilitation





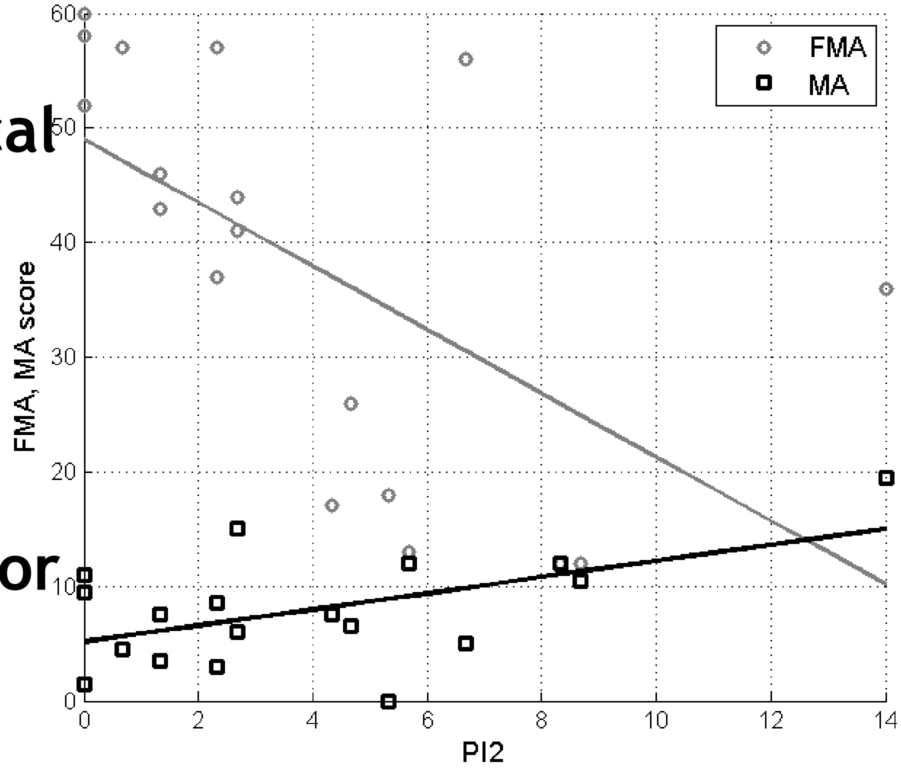
Performance indexes that correlates with increased performance

- Time execution: this can be automatically extracted from recorded motion and it is a measure of efficiency of movement execution
- Count of minima in the velocity profile: index of smoothness



Correlations

- These data correlates well **with clinical assessment**
- So performance time and number of velocity peaks are **predictors of FMA and clinical status of patient**
  - **We can use performance parameter to study motor function under different conditions**
- Does this mean a **better motor control→ improved motor function??**



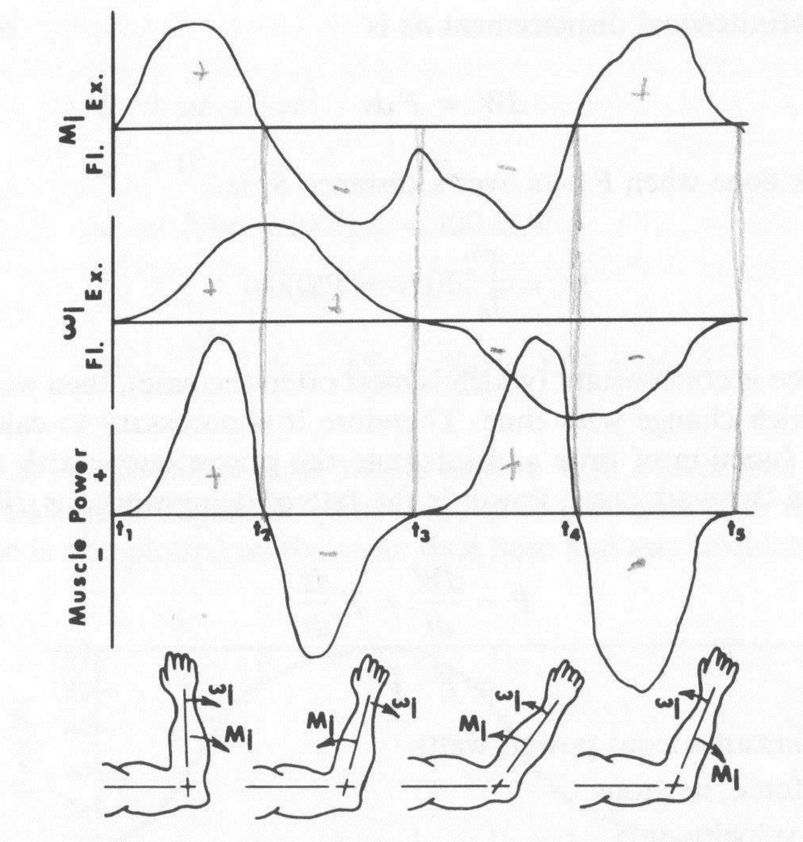
Other indexes that limit the movement execution

- Central neural mechanism are involved in the control of movement towards:
  - Planning of action: coordination among joints
  - Recruitment of different muscle patterns
  - Co-contraction ratio

- If the performance improvement is due to the above, then we can assume that **central mechanisms of learning are implied into this.**

Co- contraction index

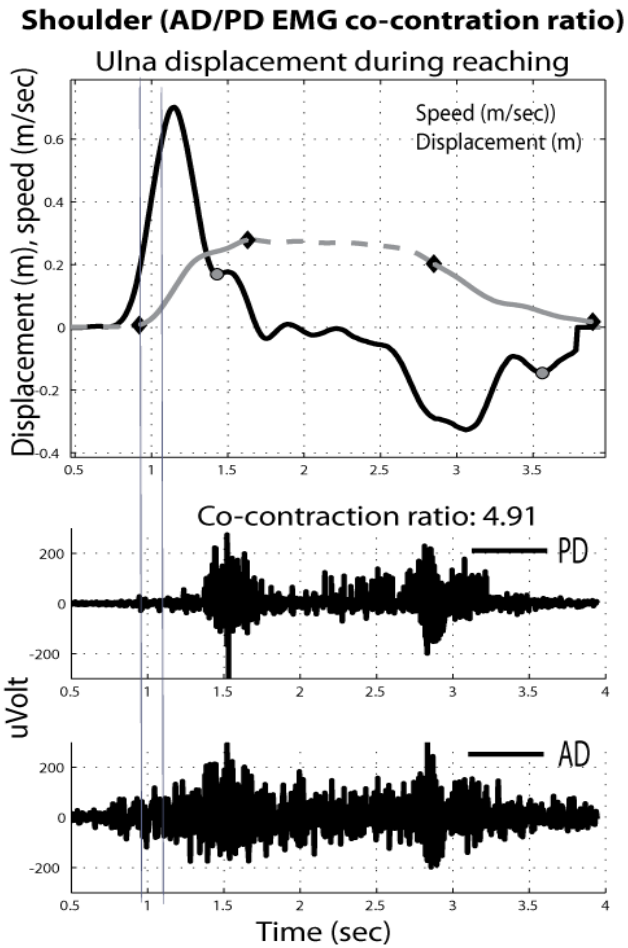
- In this diagram we can see that:
  - Muscle power has two positive peaks and two negative peaks
- Among the causes of inefficiency of the movement includes the co-contraction
- Equivalent joint combinations:
  - 30 Nm flexor
  - 40 Nm flexion, extension 10 Nm
  - 50 Nm flexion, extension 20 Nm
- The co-contractions are present in many diseases, especially hemiplegia and cerebral palsy

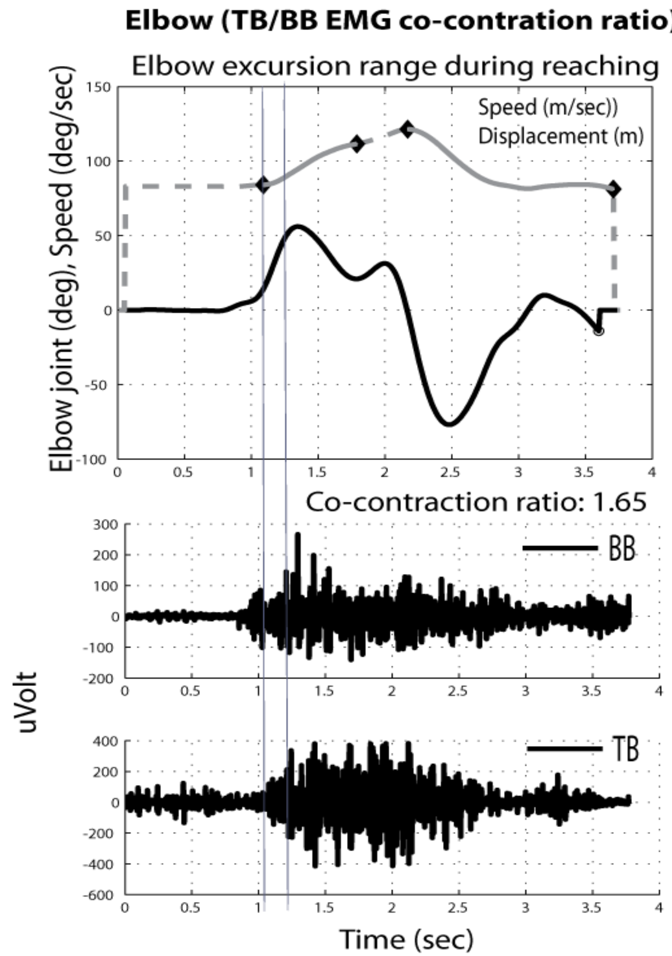


$$\mathrm{CCI\ (ag/ant)} = \frac{EMG_{ag,RMS}}{EMG_{ant,RMS}} = \frac{\sqrt{\int_{t_1}^{t_2}\left[EMG_{ag}\right]^2 dt}}{\sqrt{\int_{t_1}^{t_2}\left[EMG_{ant}\right]^2 dt}}$$

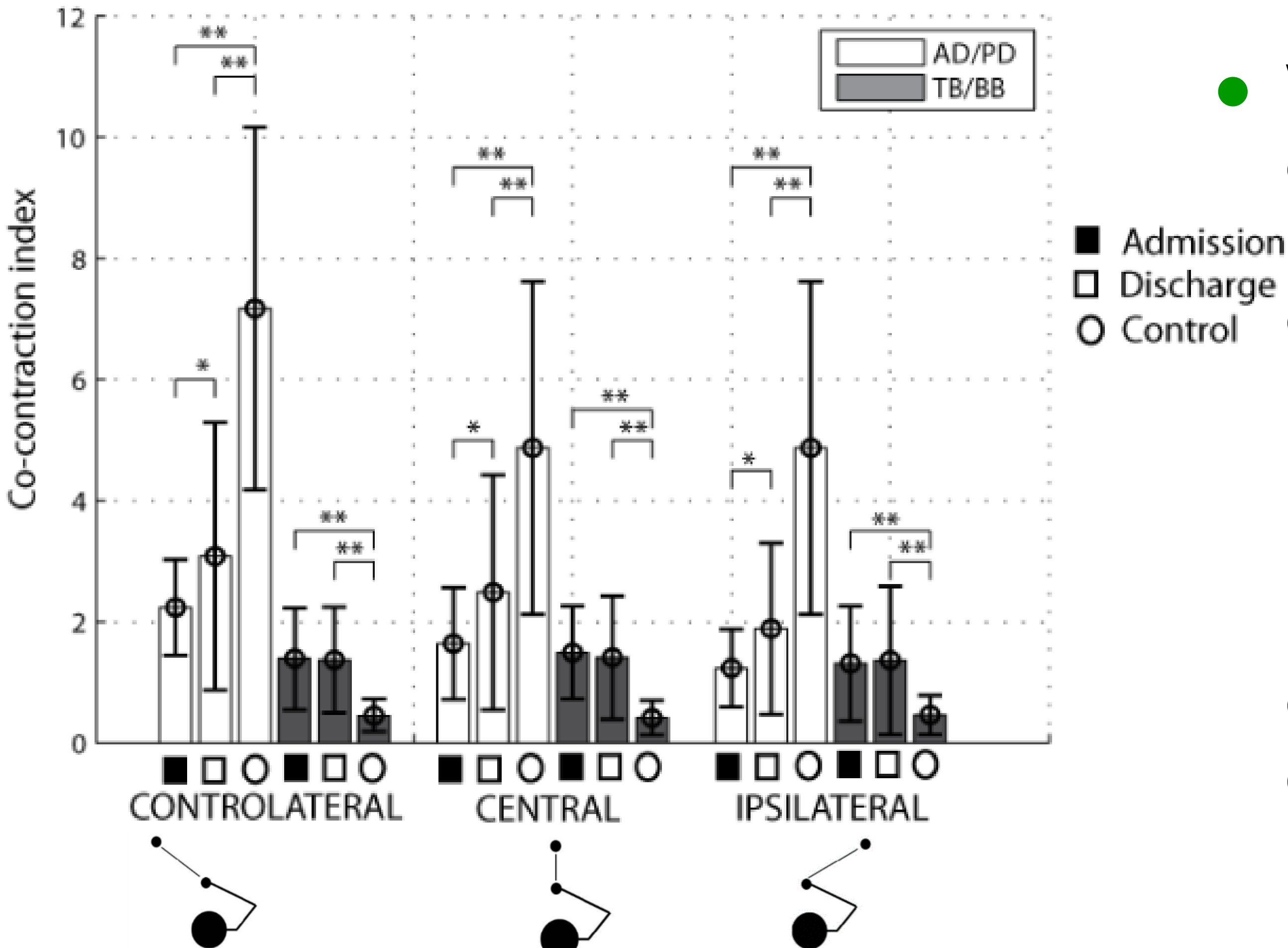
EMG co-contraction ratio computation

- Example of computation of co-contraction indexes associated to ulna displacement and elbow variation





EMG analysis summary



- We see that the effect of training results in dynamic conditions of movement in a more efficient recruitment of muscle for extension/flexion of shoulder.

Antonio Frisoli*, et al (2012). Positive effects of robotic training of upper limb reaching movements to a virtual target after stroke. Journal of Neuroengineering and Rehabilitation

EFFECT OF MOTOR SYNERGIES

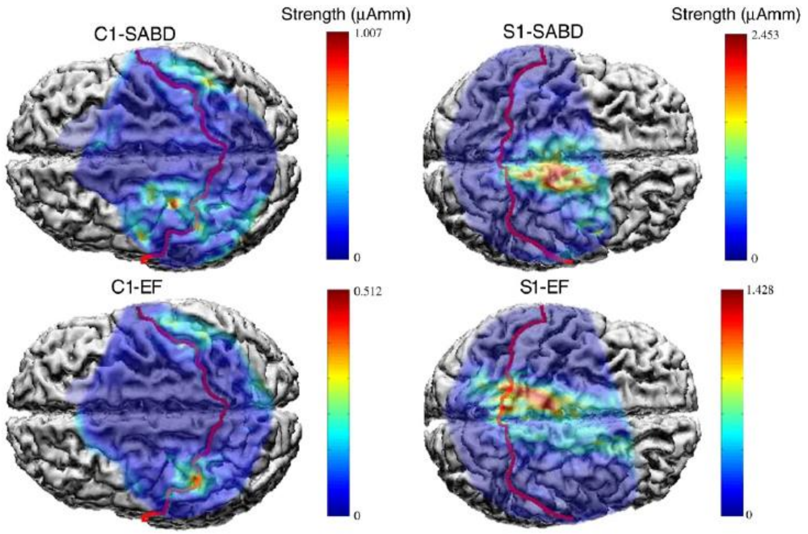
Focus on the restoration of functional movement: motor synergies

- Hemiparetic patients can exhibit abnormal joint coupling between shoulder and elbow joints (Brunnstrom 1970). Recovery of movements from stroke in the upper extremity begins with the development of a flexor synergy (shoulder abducation-elbow flexion) followed by an extensor synergy (shoulder adduction- elbow extension) pattern (Cuccurullo 2004), while isolated joint movements remain still compromised.
- In fact, only in the later stages of recovery from stroke, the reduction of the spasticity makes the patient able to make movements out of synergy and single joint movements. This deficit in single-joint control may result into a disruption of movement in terms of the required interjoint coordination (Levin, 1996 #44).

Di Pietro, Krebs et al, (2009) Changing Motor Synergies in Chronic Stroke, J Neurophysiology

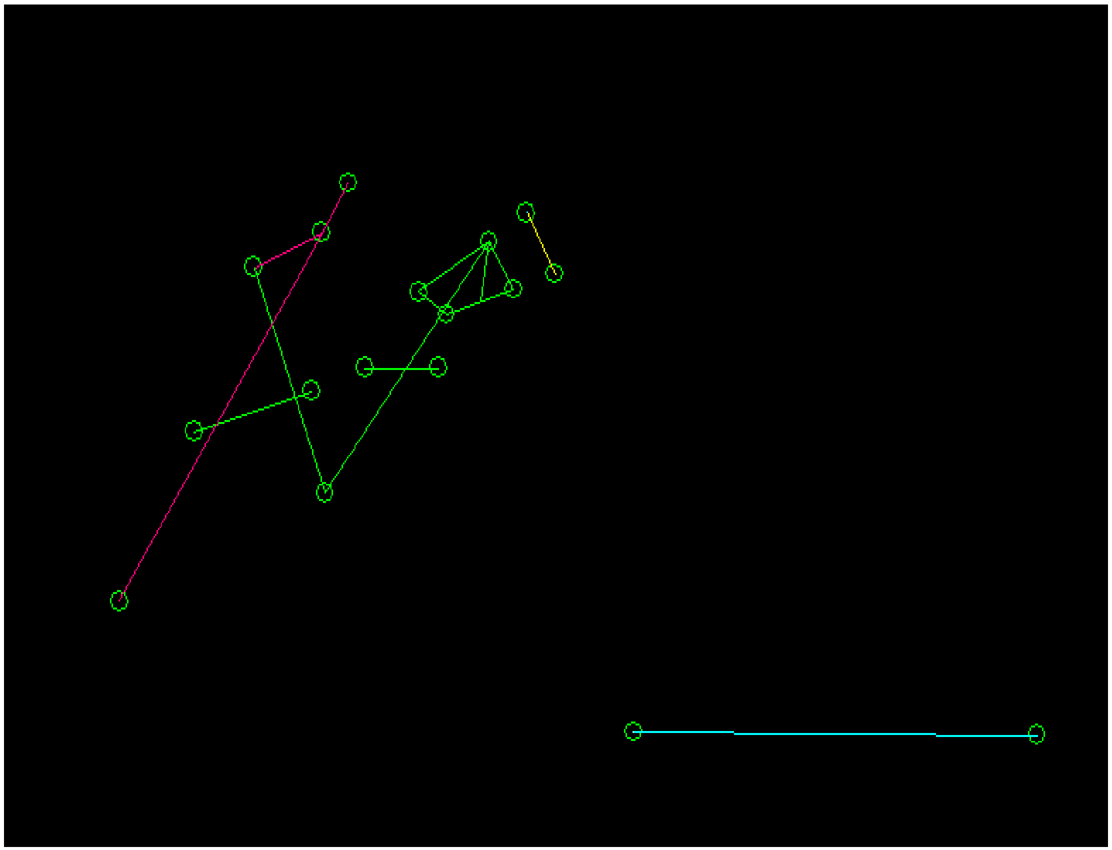
Cortical overlap of joint representations contributes to the loss of independent joint control following stroke

- Recent scientific evidences shown that there are significant increases in the overlap of shoulder and elbow joint representations at the cortical level in stroke subjects as compared to control subjects, measured by means of measured electroencephalographic (EEG) and torque signals during the generation of static shoulder/elbow torques.
- Can VR robotic therapy leads to a reduction of this overlap?



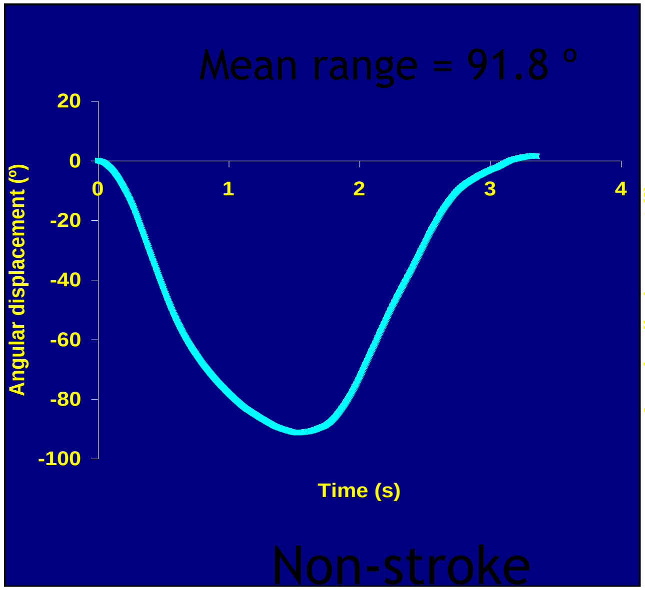
Yao, Chen (2009), Neuroimage

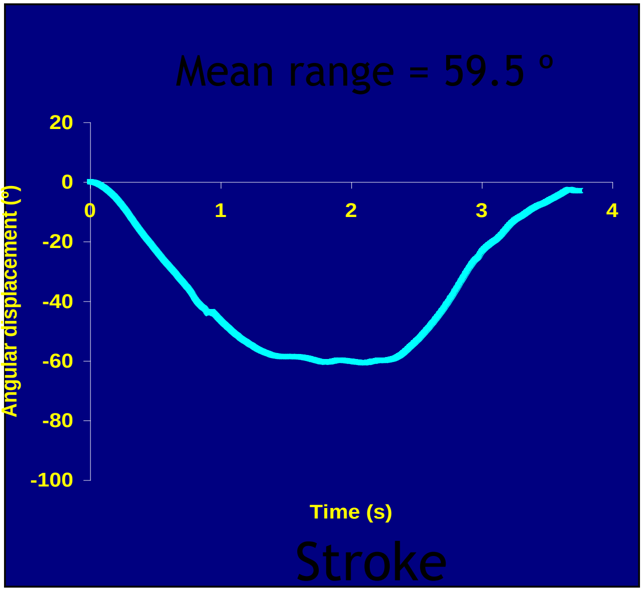
Upper limb drinking motion



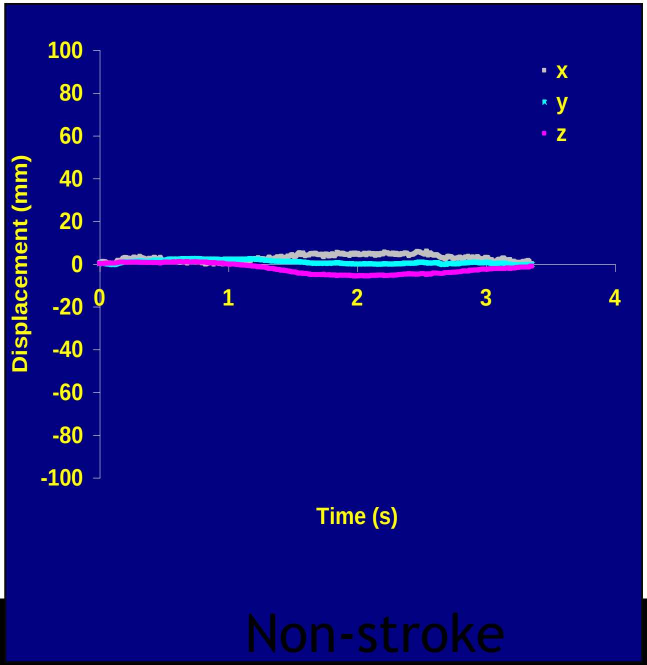
Marker	Marker name
1	C3
2	C7
3	T12
4	Acromian
5	UArm wandP
6	UArm wandD
7	Lateral epicondyle
8	LArm wandP
9	LArm wandD
10	Radial styloid
11	Ulna styloid
12	3mcp
13	5mcp

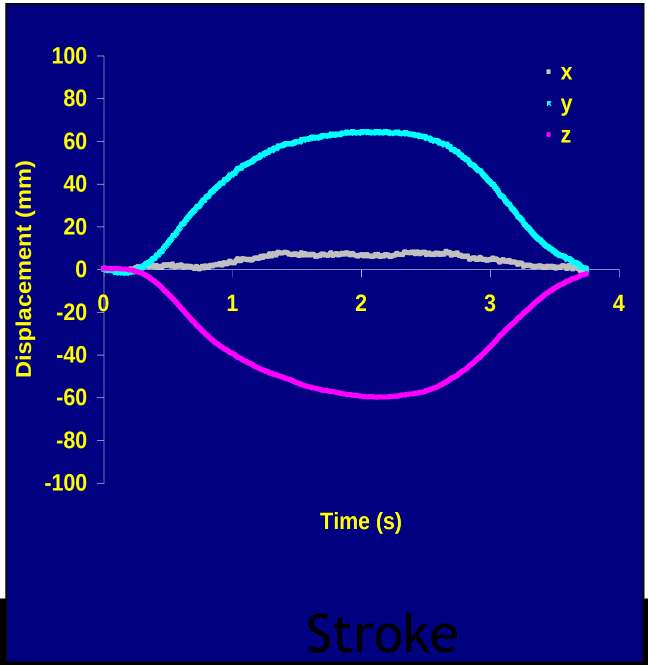
Elbow Flexion / Extension



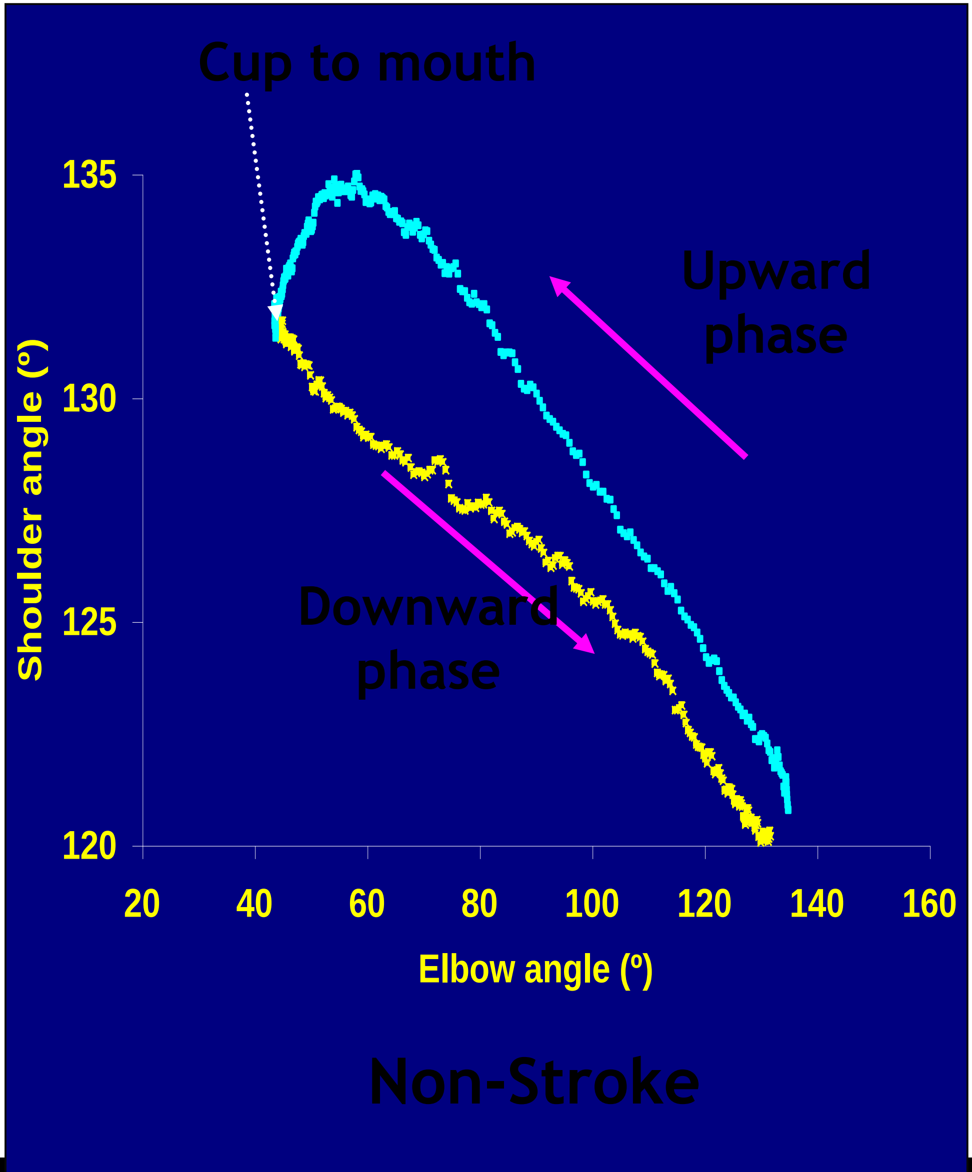


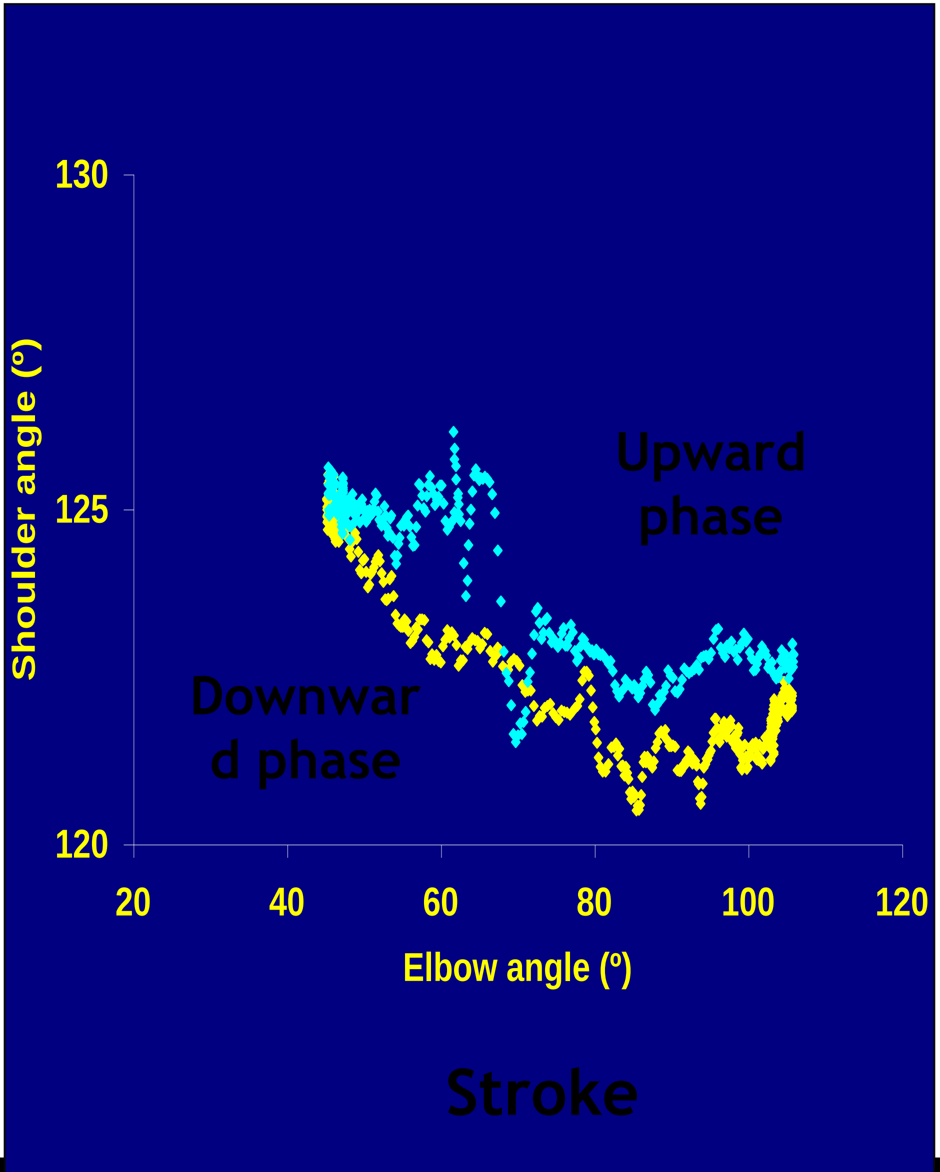
Trunk (T12) Deviation





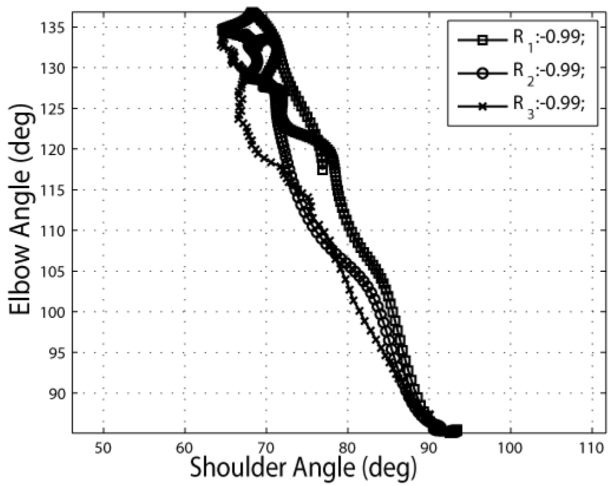
CODA - angle angle plot



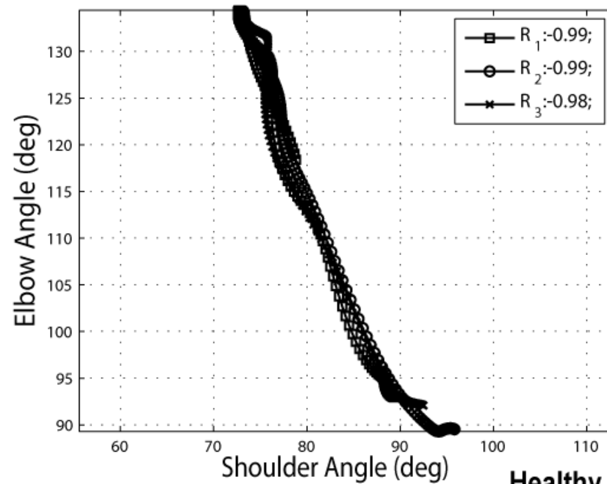


Towards a contralateral target

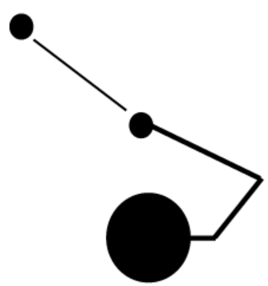
Pt. Admission



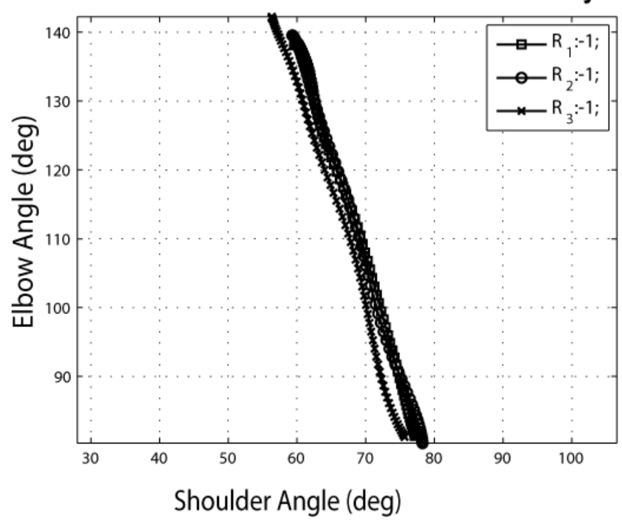
Pt. Discharge



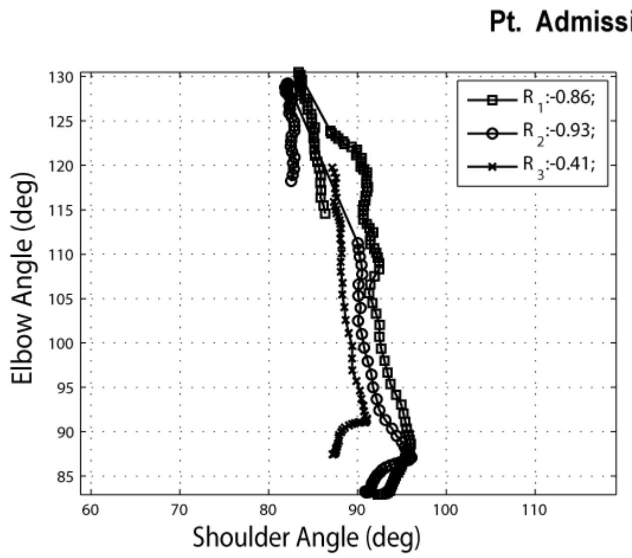
CONTRALATERAL TARGET

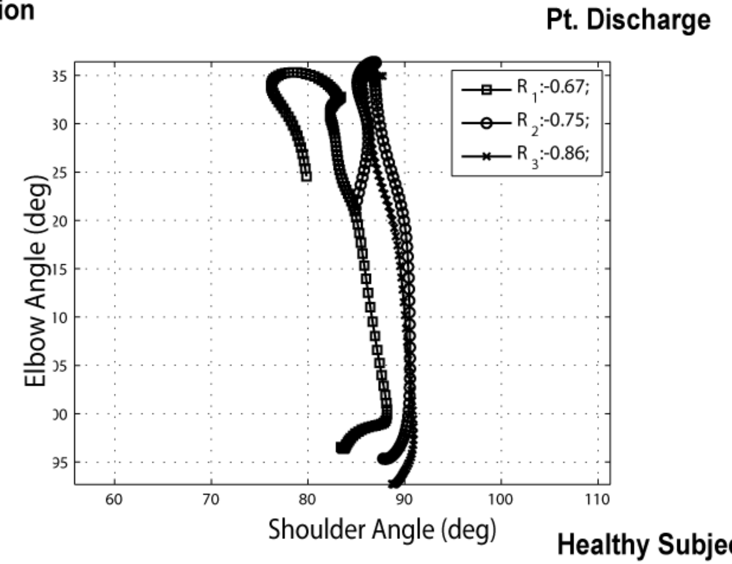


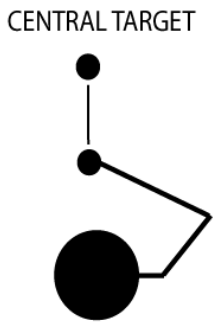
Healthy Subject

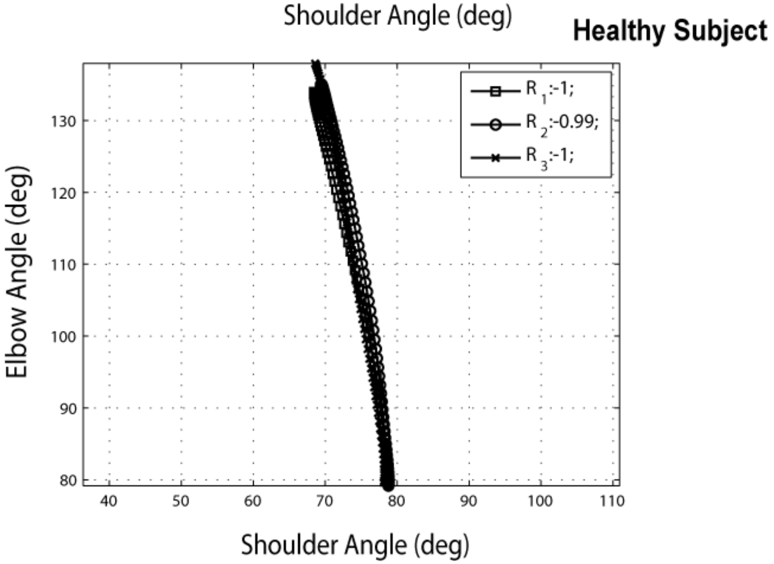


Towards a central target



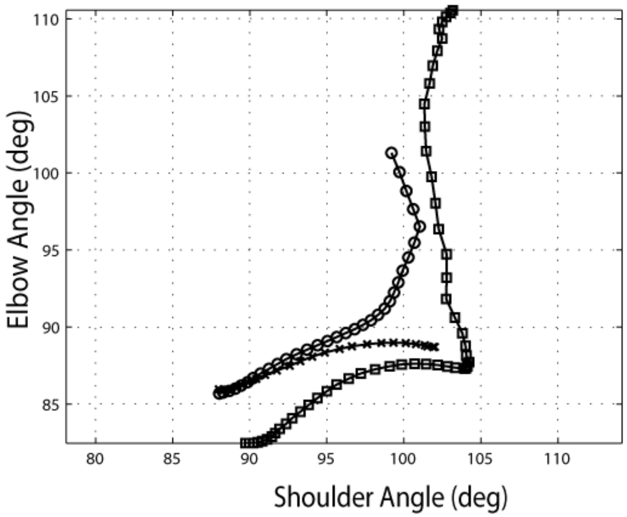




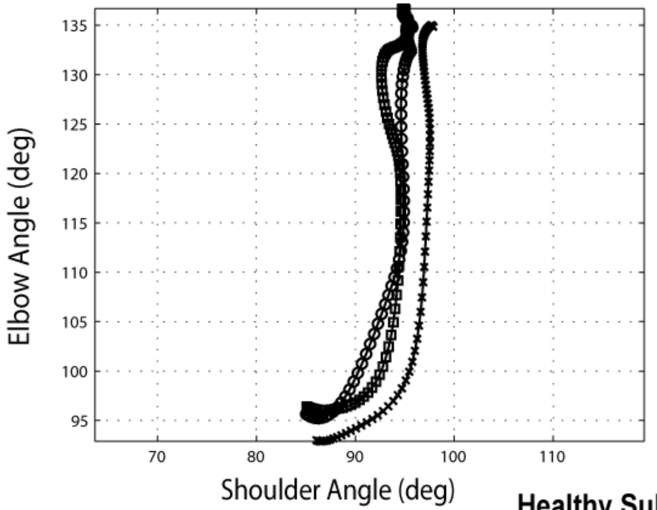


Towards an ipsilateral target

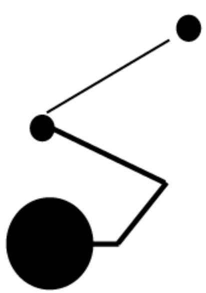
Pt. Admission



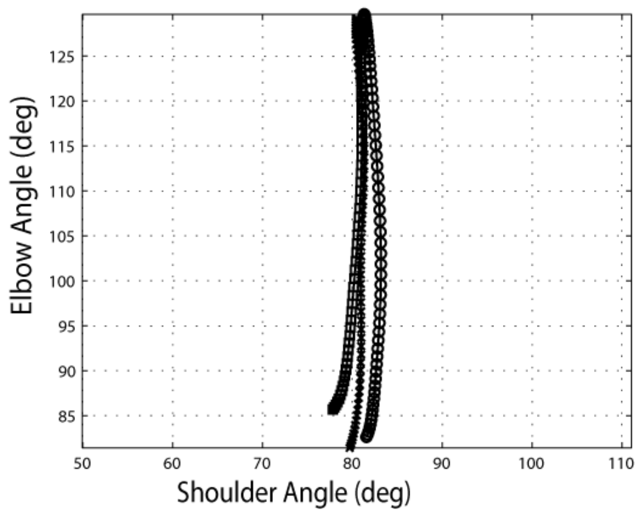
Pt. Discharge



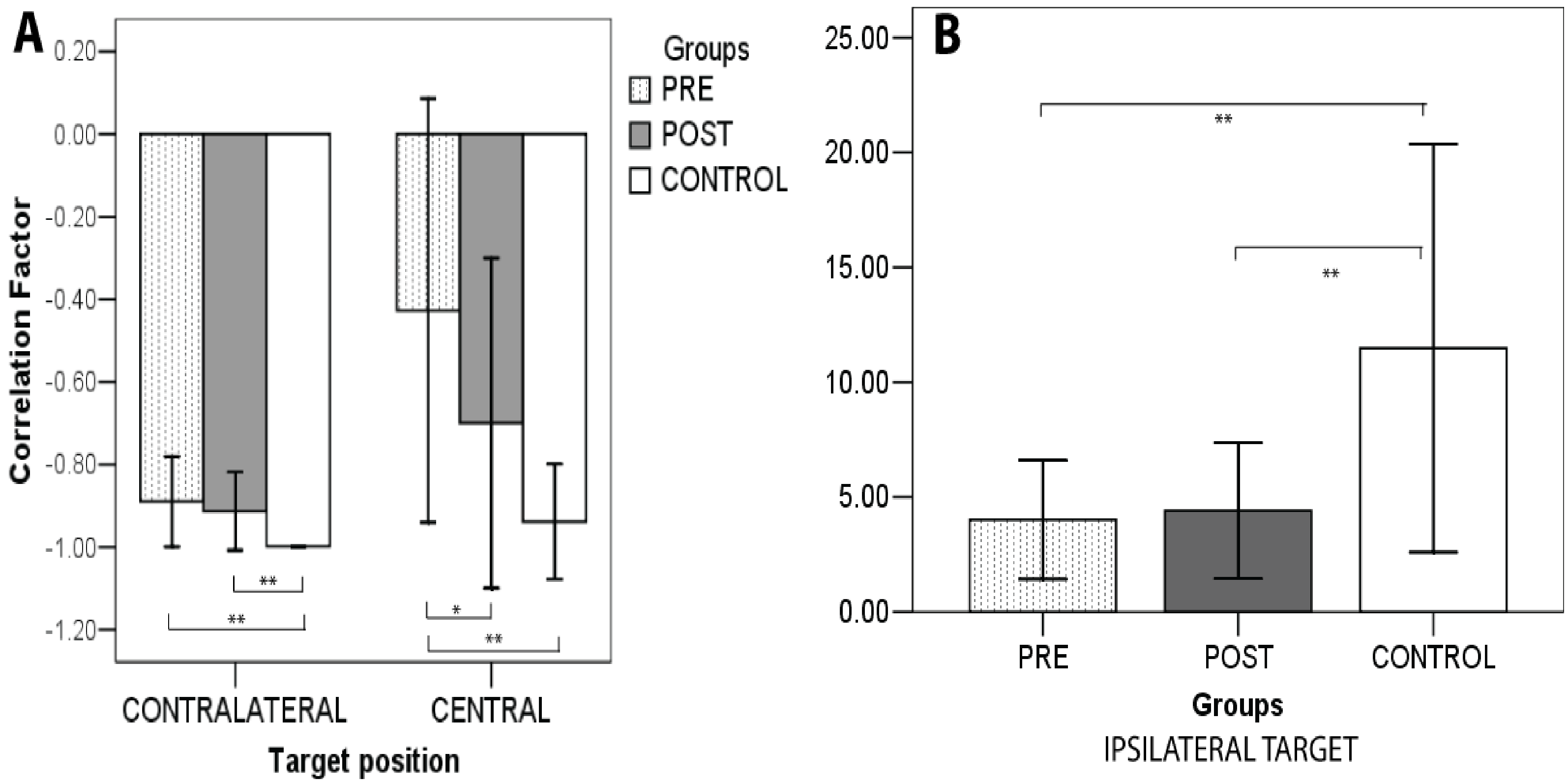
IPSILATERAL TARGET



Healthy Subject



Effects of motor synergies



Antonio Frisoli*, et al (2012). Positive effects of robotic training of upper limb reaching movements to a virtual target after stroke. Journal of Neuroengineering and Rehabilitation

Objectives of this study

- Evaluate the transfer to ADLs
  - How can we effectively evaluate the transfer to every day activity
    - Introduction of functional evaluation (bimanual activity scale)
    - Follow-up at 5 months clinical evaluation to assess retention
- Comparison with physical therapy
  - Controlled study
    - Control group performing manual therapy with a vocational approach matched for intensity and duration
- Continuous robot based evaluation of performance
  - How to achieve a continuous evaluation Automatic robotic evaluation of patient performance
  - Assessment of patient involvement with adaptive controller
    - Development of an active guidance system with adaptive behavior based on force exerted by the patient

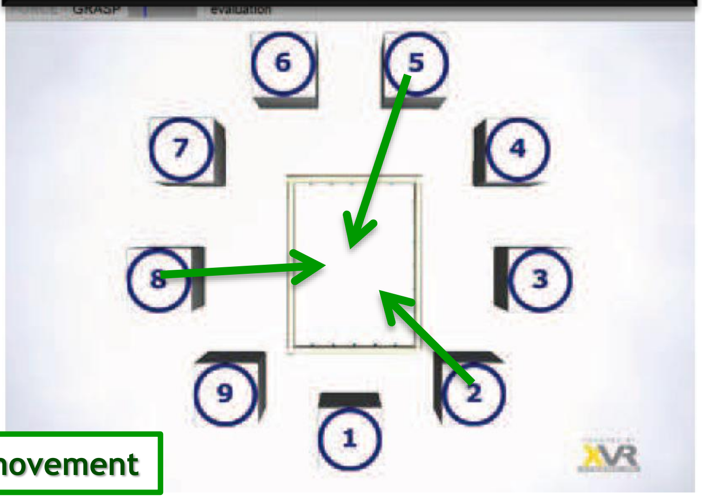
The cubes game

- Treatment session
  - in a 3D virtual environment the patient is asked to redo the puzzle shown in the central position; the cubes are randomly placed around the picture. The game is over when the patient finishes the whole puzzle.

Training

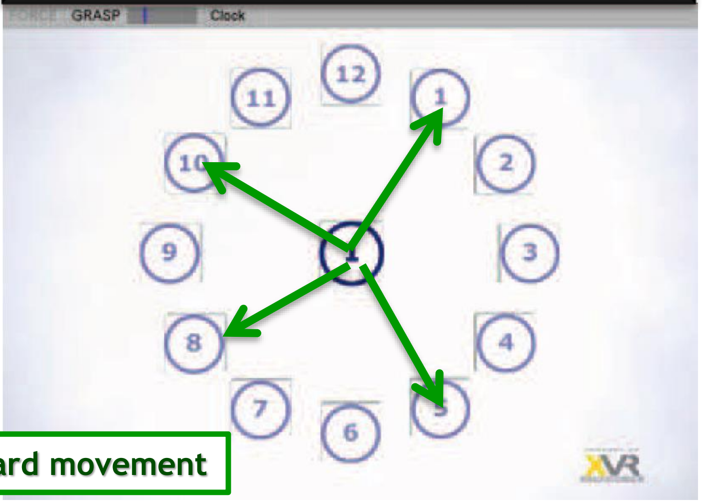
- Evaluation session
  - in the same environment the patient is asked to perform two similar task in which he/she has to move sequentially the cubes, from the periphery to the center (Basket exercise) and vice versa (Clock exercise).

Evaluation #1



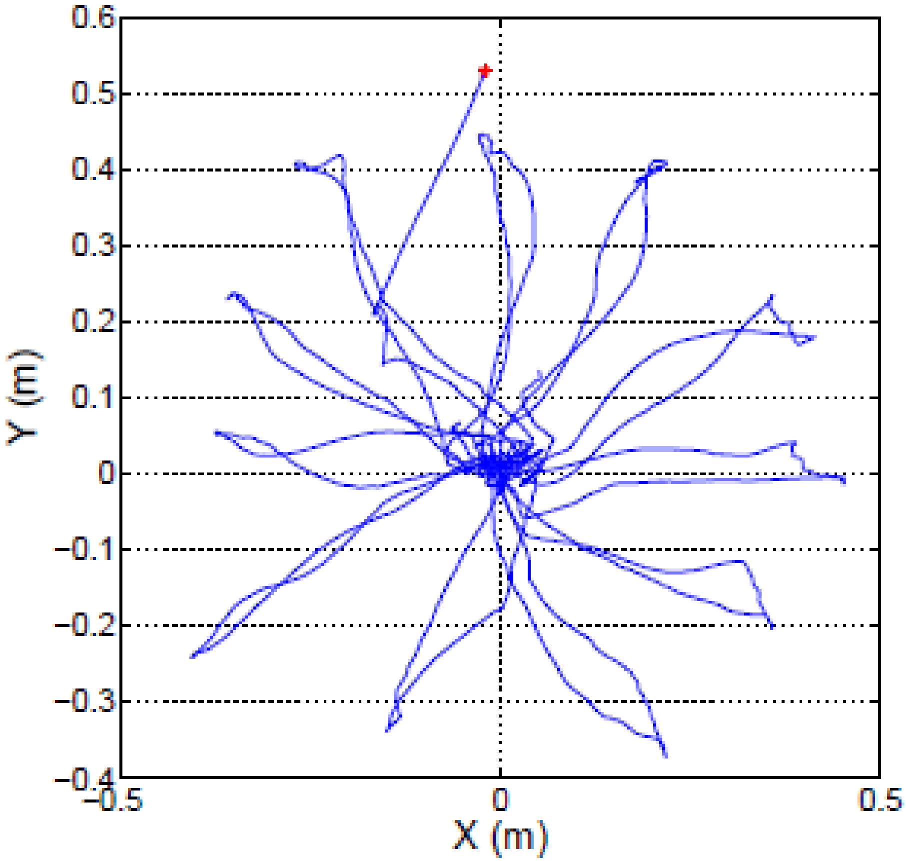
Inward movement

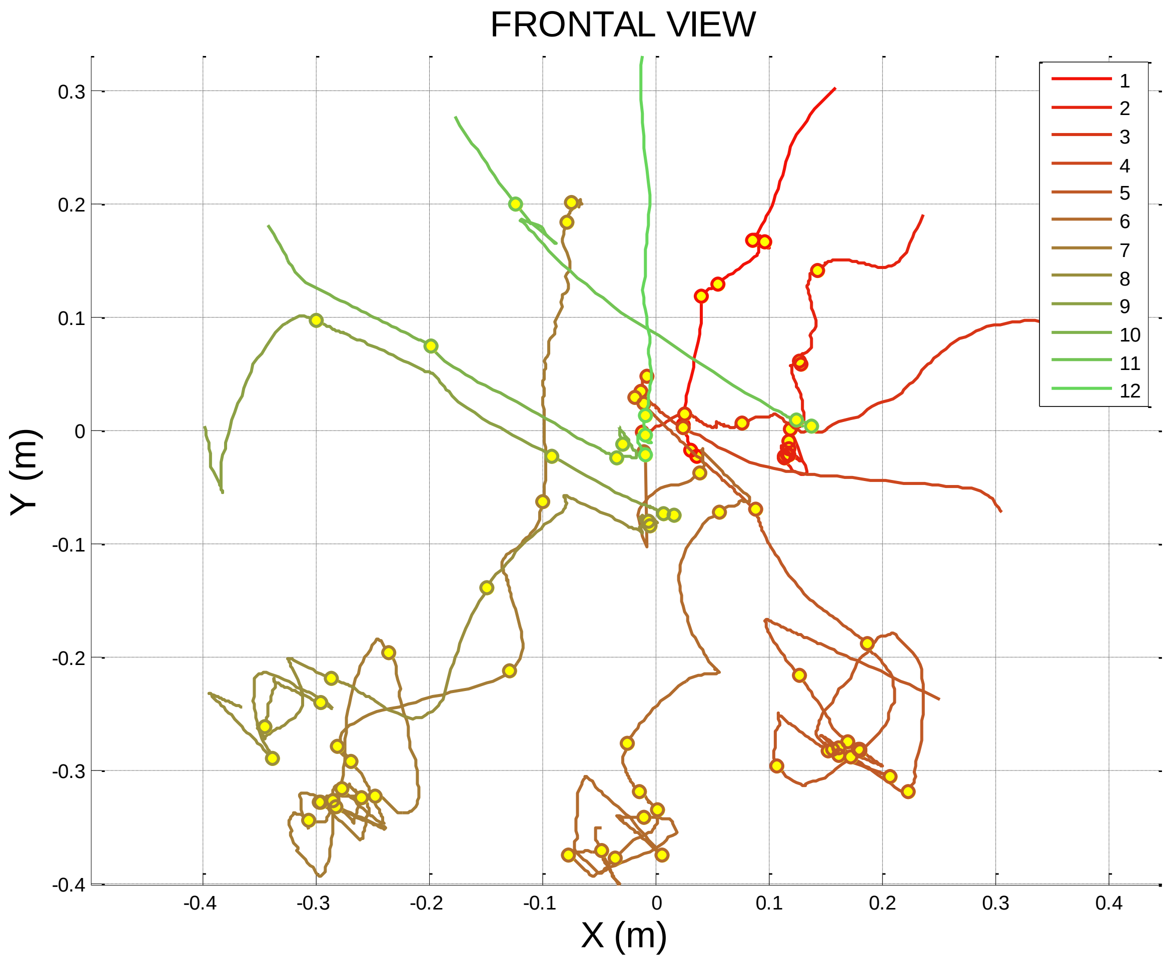
Evaluation #2



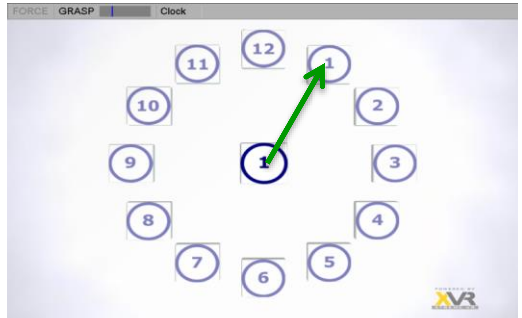
Outward movement

Performance on an healthy user



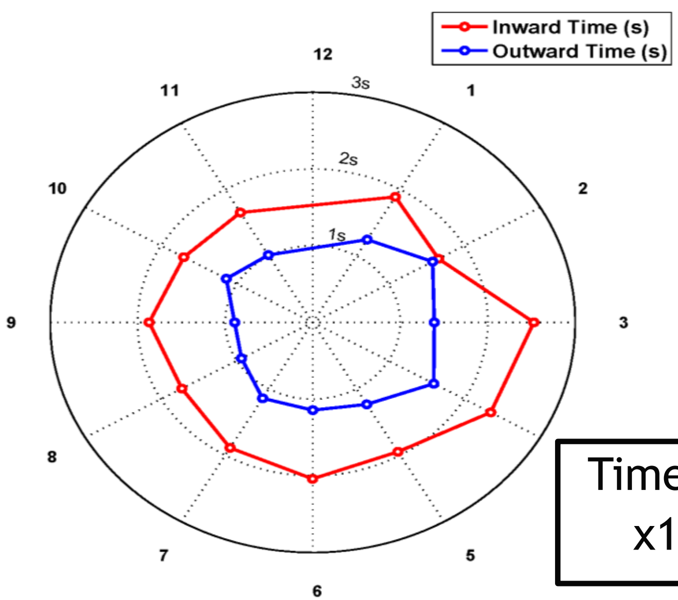

FRONTAL VIEW
Y (m)
X (m)
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
1
2
3
4
5
6
7
8
9
10
11
12

Automatic assessment of performance by means of polar plots



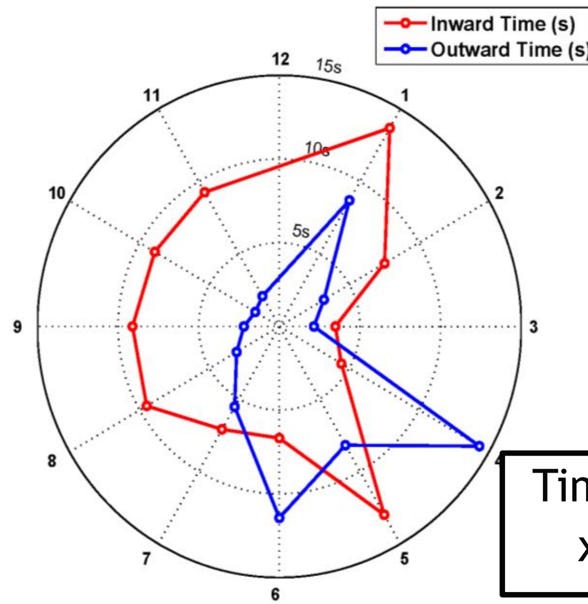
Move from center to periphery

Healthy volunteer



Time scale x1 sec

Patient Performance



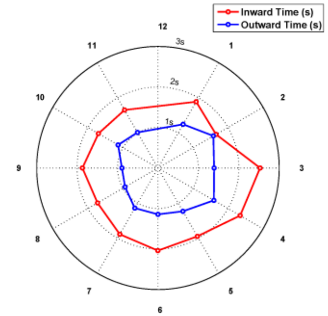
Time scale x5 sec

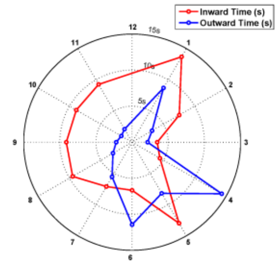
We can see here the time necessary to achieve the goals of patients moving from center to periphery and from periphery to center.

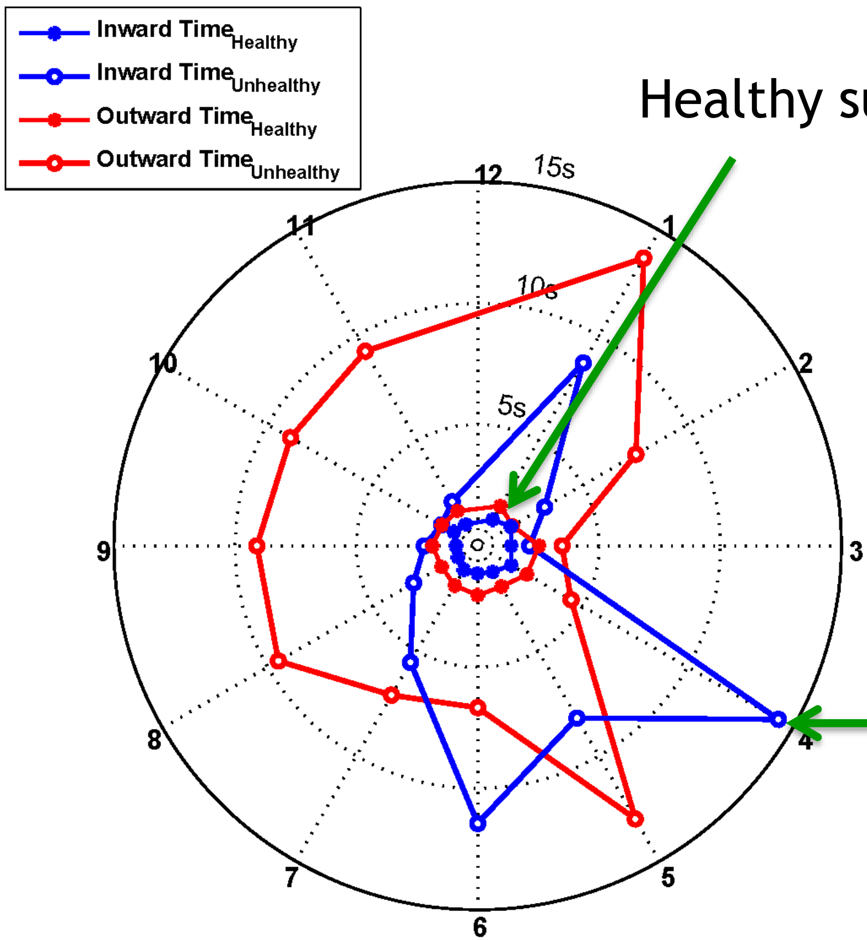
SKILLS Multimodal Interfaces for Capturing and Transfer c

PERCRO Perceptual

Sovrapposizione prestazione







Healthy subject

Patient doing the same task

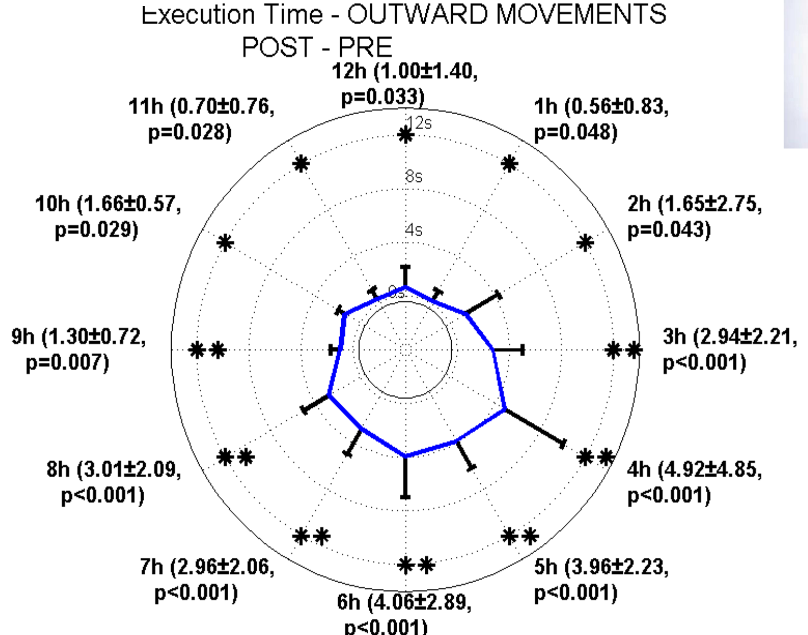
- The overlay of plots shows the difference in performance time a nd accuracy

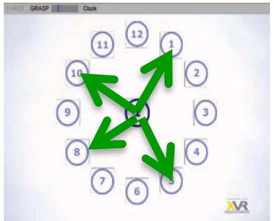
Changes in motor performance in space

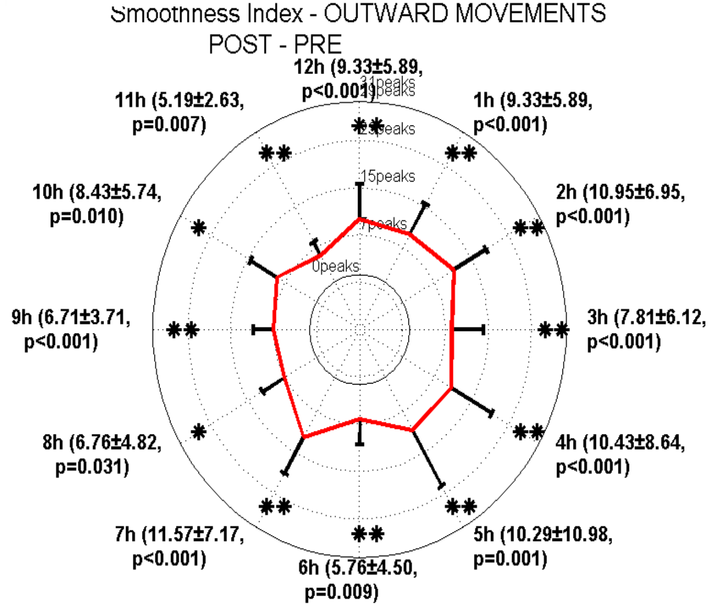
- Improvement of smoothness index and time execution observed along different direction from central position (** p<0.01, * p<0.05)

TIME

SMOOTHNESS INDEX



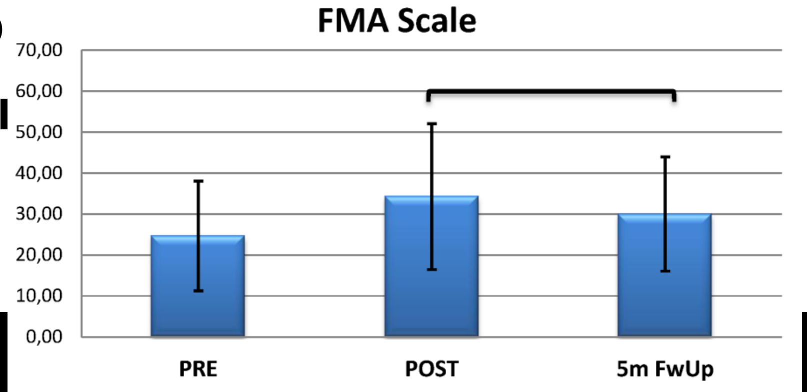




Frisoli, A., Mottet, D., Laffont, I., & Bergamasco, M. (in press). Training platforms for Upper Limb Rehabilitation. In M. Bergamasco, B. G. Bardy, & D. Gopher (Eds.), Skills training in multimodal virtual environments. Boca Raton (FL, USA): Taylor & Francis.

Conclusions

- The observed regain of function in patients after robotic therapy is consistent with neural plasticity and motor learning
- Robotic assessment correlates well with functional scale
- Clinical evaluation with interpretative scales is not precise: improvements come from functional evaluation and performance based evaluation that can provide quantitative and objective measurements
- Compared to physical therapy, robotic therapy leads to comparable increments in terms of clinical scale, BUT **higher improvements are observed in terms of improvement of shoulder and elbow motor functio**
- Motor skills are **retained over a pe** **confirmed by the follow-up**



ANALYZING LATERAL SHIFT THROUGH EEG SENSORY-MOTOR ANALYSIS

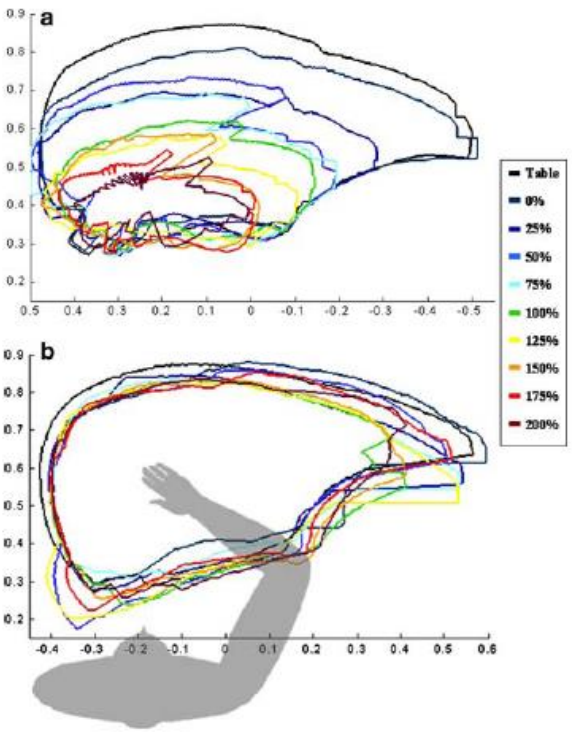
ISTITUTO DI TECNOLOGIE DELLA COMUNICAZIONE, DELL'INFORMAZIONE E DELLA PERCEZIONE

Scuola Superiore Sant'Anna

PERCRO Perceptual Robotics Laboratory

Arm load support can enlarge workspace

- There are proofs in literature that gravity compensation leads to a recovery of motor abilities.
  - Rekensmeyer et al. (2006) The first study demonstrated that individuals with chronic stroke whose arm function is compromised in a normal gravity environment can perform reaching and drawing movements with gravity compensation. It has been demonstrated that exercising the affected arm over an eight week period improved unassisted movement ability
  - Envelope abilities during various levels of limb support in the left, paretic limb (a) of a single subject, inverted for comparison to the non-paretic limb shown in (b). Axes units are in meters, and an individual’s outline is provided in the non-paretic (right) side for reference (“Shoulder abduction-induced reductions in reaching work area following hemiparetic stroke: neuroscientific implications” Exp Brain Research (2007)   Sukal, Ellis et al.



WREX , T-WREX ed Armeo

Subject	Time from stroke	Fugl-Meyer At start	Change
1	3 yr.	11	+5
2	6 yr.	19	+5
3	9 yr.	27	+3
4	4 yr.	20	+8
5	11 yr.	32	+4

- **Sistema passivo (elementi elastici)**
- **Forza anti-gravità**
- **4 GDL**

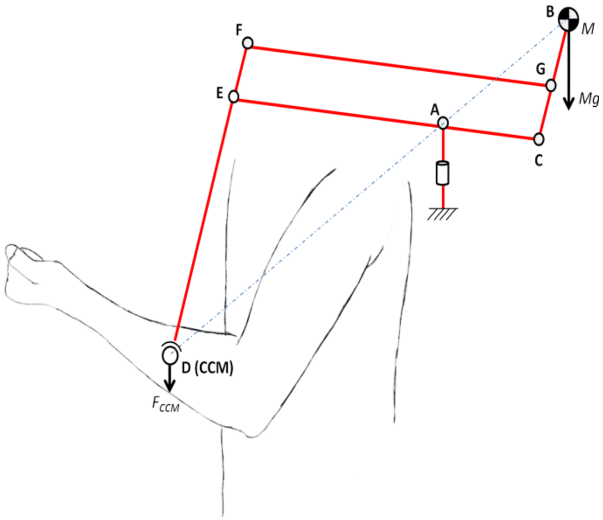
R. J. Sanchez, D. J. Reinkensmeyer et al. Automating Arm Movement Training Following Severe Stroke: Functional Exercises With Quantitative Feedback in a Gravity-Reduced Environment. IEEE TRANSACTIONS ON NEURAL SYSTEMS AND REHABILITATION ENGINEERING, VOL. 14, NO. 3, SEPTEMBER 2006


Stroke patient

Track-hold system

Trackhold: a novel passive arm-support device

- The Trackhold is conceived in order to
  - allow the measurement of the three components of position and the three components of orientation of the supported arm **(Track)**
  - at the same time, provide static balancing of the user arm self weight regardless of the configuration **(Hold).**
- The Trackhold employs a simple arm-balancing technique which aims at minimizing the joint torques (on shoulder and elbow joints)
  - **The working principle is based on the concept of the Combined Center of Mass (CCM).**



- The arm kinematics is modeled with a spherical joint at the level of the shoulder and a rotational joint at the level of the elbow.

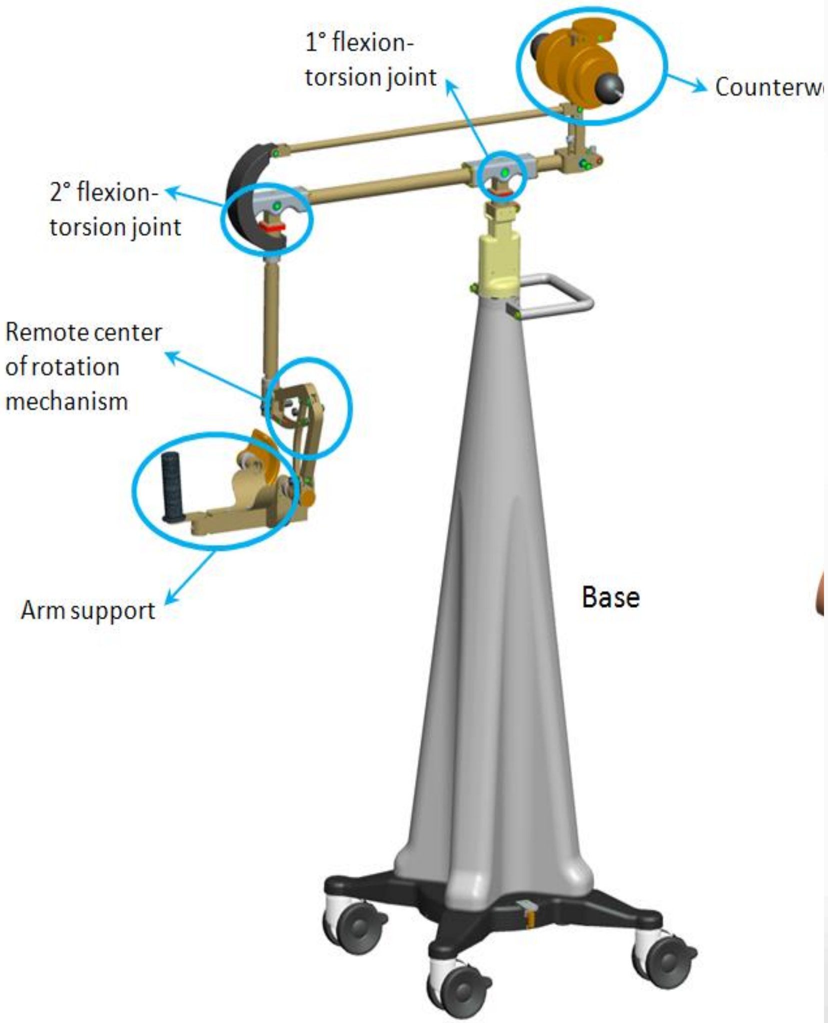
$$\boldsymbol{\tau} = J_1^T \mathbf{p}_1 + J_2^T \mathbf{p}_2 + J_c^T \mathbf{f}$$

$$\boldsymbol{\tau} = \begin{bmatrix} 0 \\ (m_2 g d_2 - f_z d_c) s_{\beta 2} s_{\beta 34} + (m_2 g l_1 + m_1 g d_1 - f_z l_1) s_{\beta 2} s_{\beta 3} \\ -(m_2 g d_2 - f_z d_c) c_{\beta 2} c_{\beta 34} - (m_2 g l_1 + m_1 g d_1 - f_z l_1) c_{\beta 2} c_{\beta 3} \\ c_{\beta 2} c_{\beta 34} (f_z d_c - m_2 g d_2) \end{bmatrix}$$

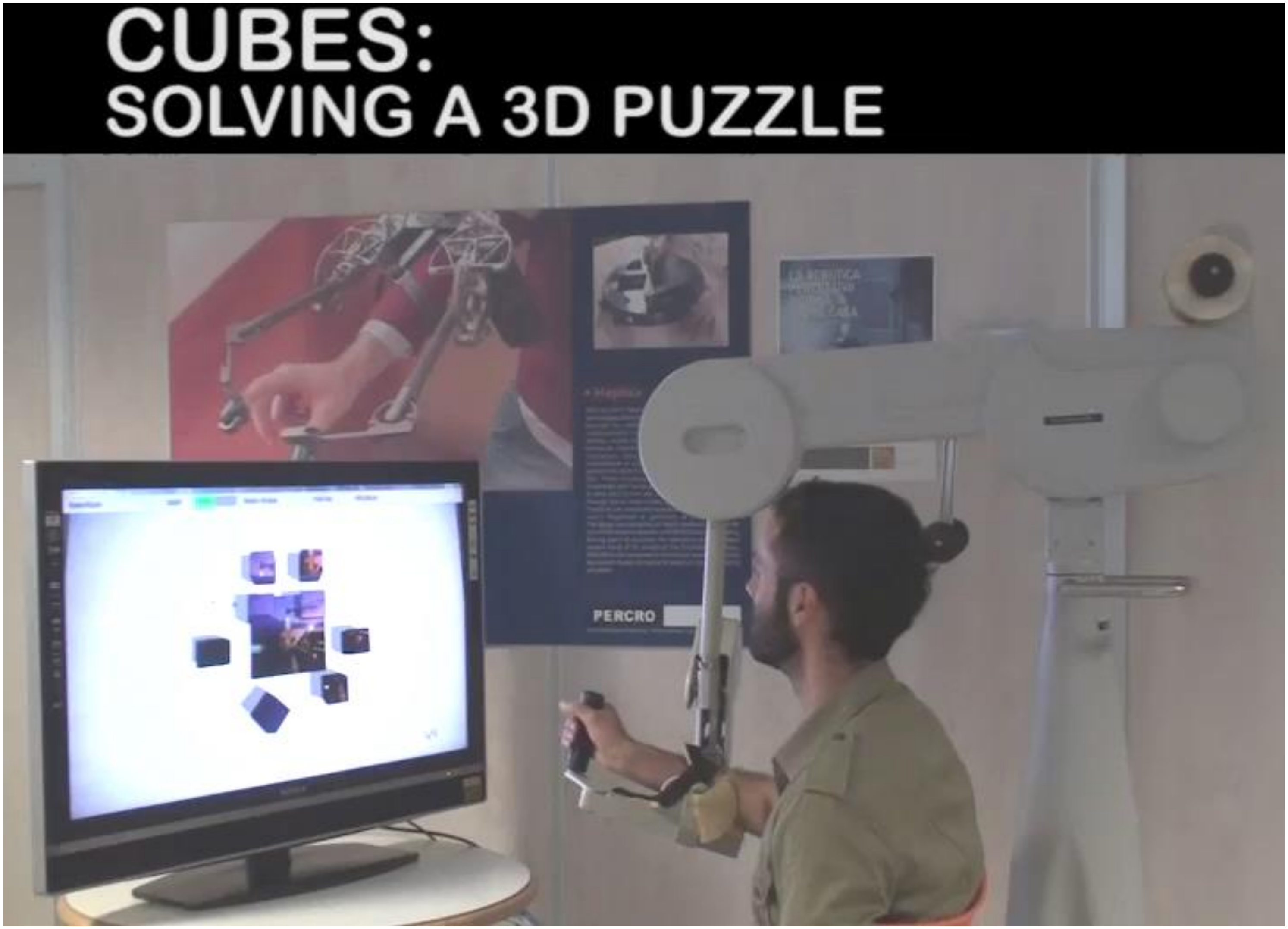
- The optimal balancing condition is obtained imposing τ=0. Regardless of the configurations β_i,

$$\mathbf{f} = -\left(\mathbf{p}_2 + \mathbf{p}_1 \frac{d_1}{l_1} \right)$$

$$d_c = \frac{d_2}{1 + \frac{m_1 d_1}{m_2 l_1}}$$


1° flexion-
torsion joint
Counterw
2° flexion-
torsion joint
Remote center
of rotation
mechanism
Arm support
Base

Combination with a serious game



Application to sensorymotor activation in brain

- Three post-stroke patients with motor deficits in one upper limb were recruited at the **Private Hospital "Casa di Cura Privata Villa Serena,** clinical evaluatoin conducted by Prof. Silvia Comani,
- Neuro rehabilitation was performed with a novel system that combines a passive robotic device (Trackhold - PERCRO, Pisa, Italy) working with five dedicated VR training applications and synchronized with a HR-EEG system
- Cortical activity was recorded during rehabilitation training using a HR-EEG system including an EBN Galileo MIZARPLUS amplifier and an EBN Galileo NT acquisition software (EBNeuro, Italy), and a head-cap with 128 Ag/AgCl electrodes positioned according to the international 10-5 system (Electro-Cap International, Ohio, USA)

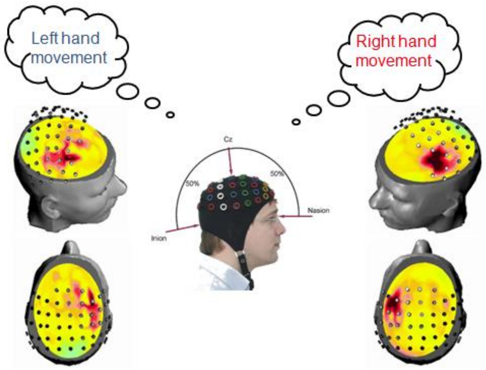
- The transformation matrices mapping the fiducials from EEG space to MRI space were used to co-register the standard sensors coordinates
- Inverse source reconstruction was performed using the multiple sparse priors (MSP) algorithm

Comani et al, 2015; IEEE TRNSE

Laterality index

- Laterality index definition
  - Q_{CL} and Q_{IL} are the intensities of the corresponsing labeled clusters respectively in the contralateral and ipsilateral hemisphere
  - LIU may range from -100 (fully ipsilateral hemisphere dominance) up to 100 (fully contralateral hemisphere dominance)

$$QI = \frac{Q_{CL} - Q_{IL}}{Q_{CL} + Q_{IL}}$$



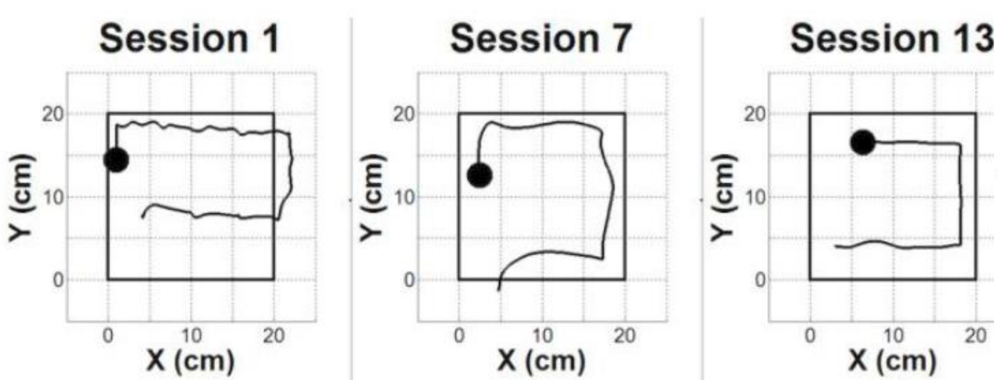
- Difference
  - These differences may have a final value that can range from - 200 (full ipsi-lateral shift) to + 200 (full contra-lateral shift).

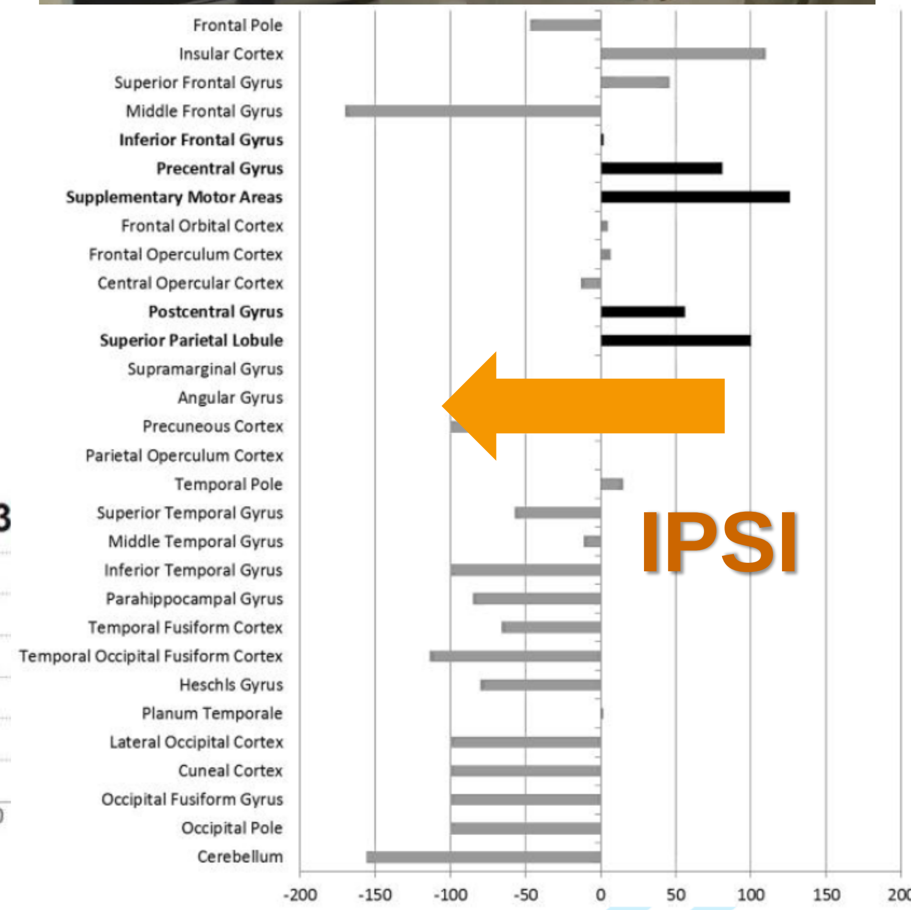
Comani et al, 2015; IEEE TRNSE

Patient #1:Sponge trackhold

- The changes of the inter-hemispheric distribution of the active areas from the first to the last rehabilitation session are quantified through the differences of the laterality index LI
- It is clear that, by the end of rehabilitation, the majority of the active regions of interest (ROIs) is characterized by a lateralization change towards the ipsilateral hemisphere, while a more contralateral shift is detected in the sensorimotor and insular cortex.

The red rectangles show the right parietal cortical lesion

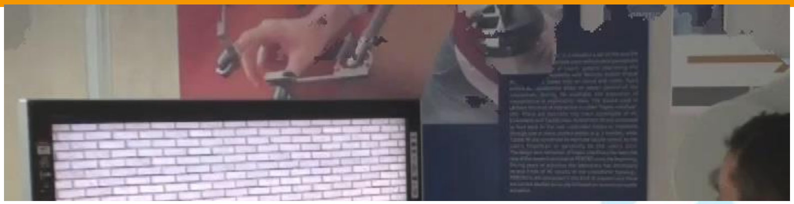




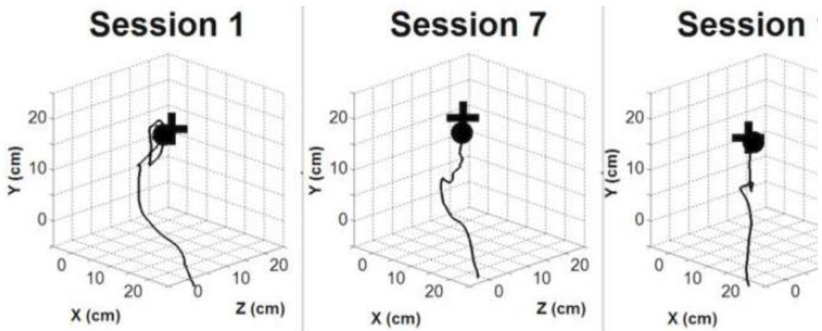
PERCEZIONE

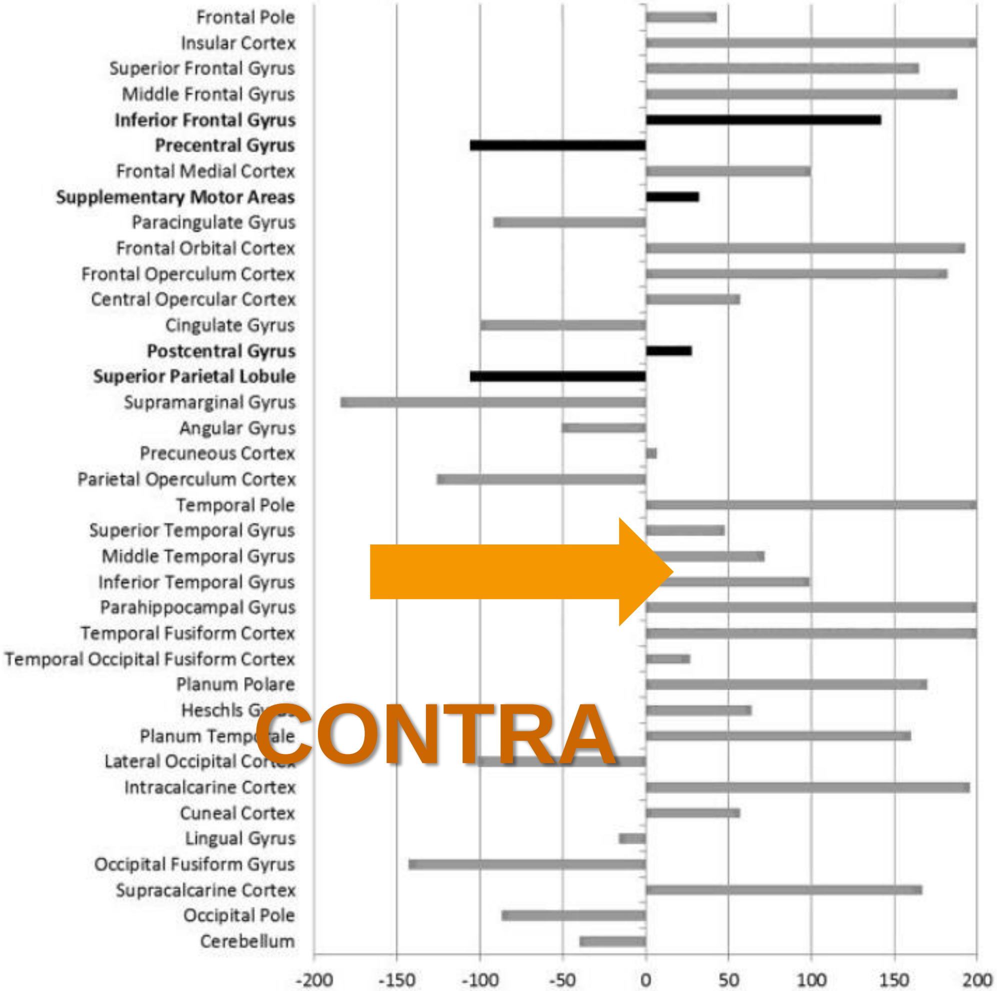
Comani et al, 2015; IEEE TRNSE

Patient #2 example of grab3d application



- The changes of the inter-hemispheric distribution of the active areas throughout rehabilitation with Grab3D are shown.
- We observe that, by the end of rehabilitation, the majority of the ROIs has undergone a contra-lateral shift. Only a small number of areas has undergone an ipsi-lateral shift.





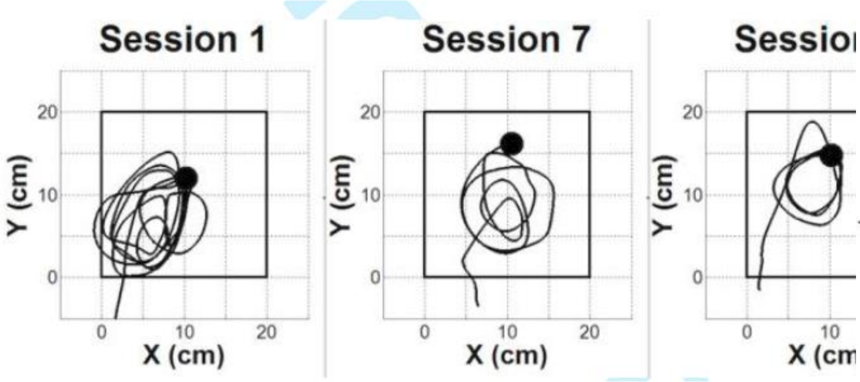
Comani et al, 2015; IEEE TRNSE

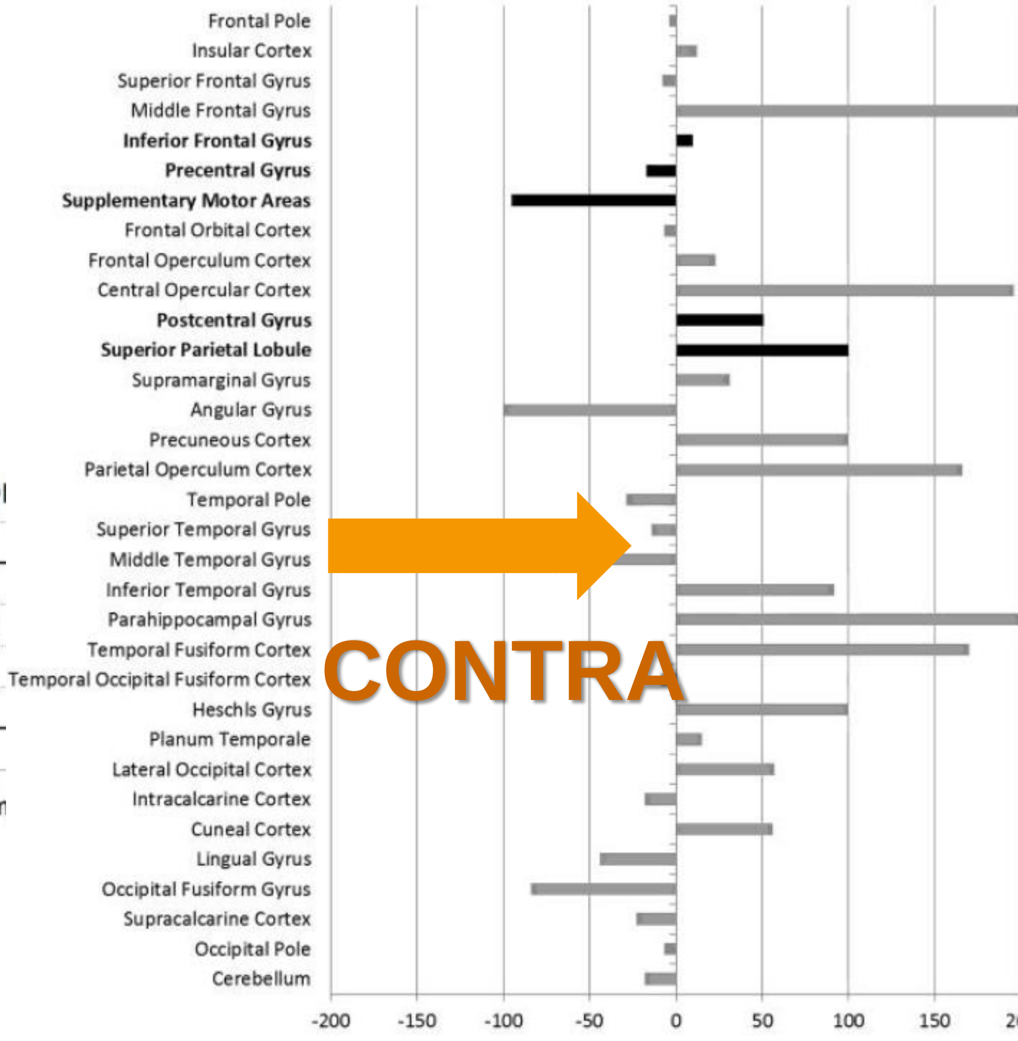
ISTITUTO DI TECNOLOGIE DELLA COMUNICAZIONE, DELL'INFORMAZIONE E DELLA PERCEZIONE

Scuola Superiore Sant'Anna

Patient #3: Twirl application

- Although there is a similar number of areas undergoing ipsi- and contralateral shifts, the amplitude of the overall contra-lateral shifts, which regard also the motor areas, was more pronounced.





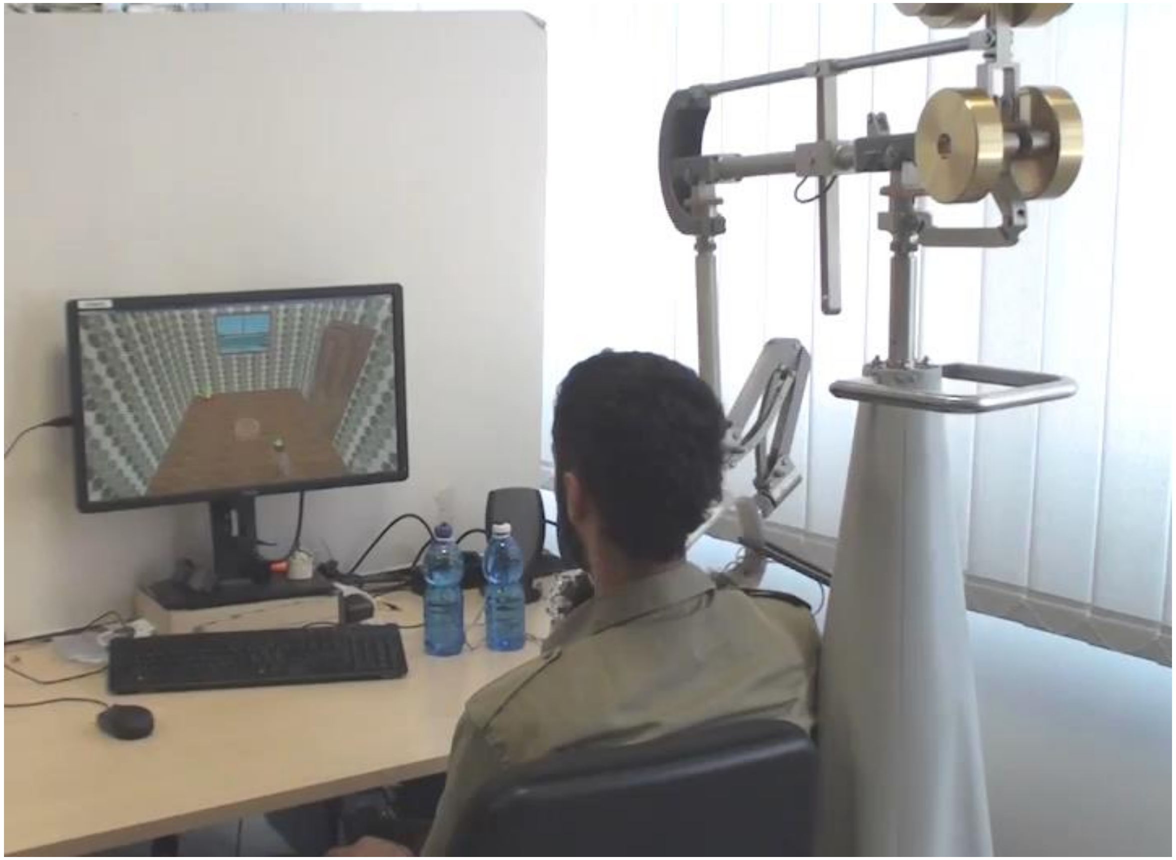
Comani et al, 2015; IEEE TRNSE

Some comments

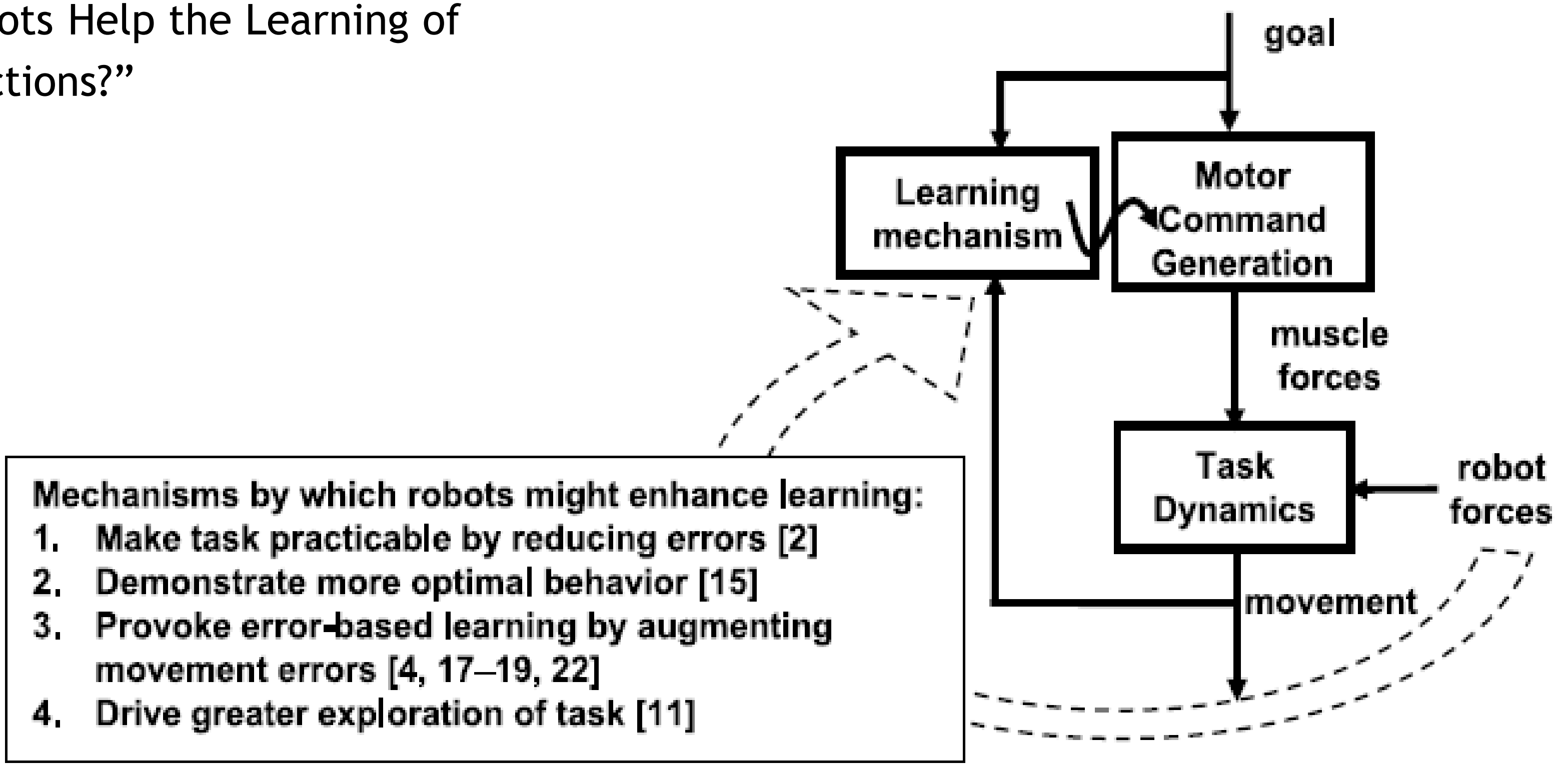
- The difficulties encountered in the identification of clear lateralization shifts can be explained:
  - Longitudinal studies have demonstrated an overall contra-lateral shift of the active motor areas in association with improved motor function
  - However, there are examples of patients showing a persistent bilateral recruitment or an ipsi-lateral shift in the motor areas
  - These findings have suggested that also the ipsi-lateral motor areas might contribute to the recovery of the motor function,

Going forwards

- Reaching and grasp with hand exoskeleton



David J. Reinkensmeyer1 and James L. Patton2
“Can Robots Help the Learning of
Skilled Actions?”



MODALITÀ DI CONTROLLO DI UN ROBOT

Crespo, Rekensmeyer (2009), Journal of NeuroEngineering and Rehabilitation

Assistance as needed

Impedance based assistance

- The first assistive robotic therapy controllers proposed were proportional feedback position controllers
- Assistive control strategies focus on a common, underlying idea: when the participant moves along a desired trajectory, the robot should not intervene, and if the participant deviates from the desired trajectory, the robot should create a restoring force, which is generated using an appropriately designed mechanical impedance. Controllers based on this principle provide a form of "assistance-as-needed",

Triggered assistance

- It allows the participant to attempt a movement without any robotic guidance, but initiates some form of (usually) impedance-based assistance after some performance variable reaches a threshold.
- This form of triggered assistance encourages participant self-initiated movement, which is thought to be essential for **motor learning**

Counterbalancing assistance

- Providing weight counterbalance to a limb is another assistance strategy that has been developed. Rehabilitation clinics have a long history of using devices to partially counterbalance the limbs, such as mobile arm supports, overhead slings, arm skateboards or towels that slide on tables, and harnesses for supporting body weight during walking.

Crespo, Rekensmeyer (2009), Journal of NeuroEngineering and Rehabilitation

EMG based assistance

- Some groups have developed robotic devices that employ surface electromyography signals (sEMG) to drive the assistance.

Performance based adaptation

- The assistive control algorithms reviewed to this point are static in the sense that they do not adapt controller parameters based on online measurement of the participant's performance. Adapting control parameters has the potential advantage that the assistance can be automatically tuned to the participant's individual changing needs, both throughout the movement and over the course of rehabilitation

Bilateral schemes

- Another strategy for determining the desired trajectory, possible for bilateral tasks, is to base the desired trajectory on the movement of the "good" limb

Research strategies

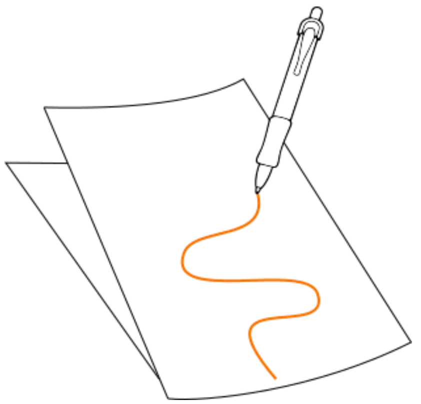
Crespo, Rekensmeyer (2009), Journal of NeuroEngineering and Rehabilitation

Resistive strategies	Constrain induced therapies	Error-amplification strategies
• Based on Proprioceptive NeuroMotor Facilitation, resistance to movement elicits activation of movement	• Some dofs of the limb or the entire limb is constrained	• Amplification of error given as feedback (e.g. visual)

Task typology for rehabilitation

Trajectory driven tasks

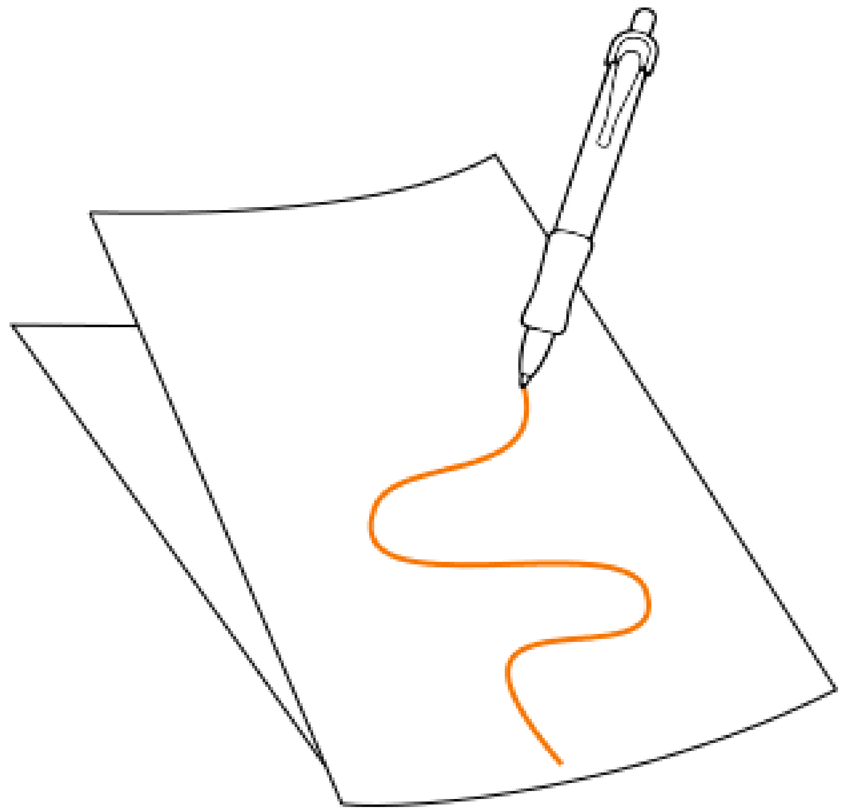
- Follow a target
- Predefined trajecory
- Predefined speed
- Draw a geometric shape



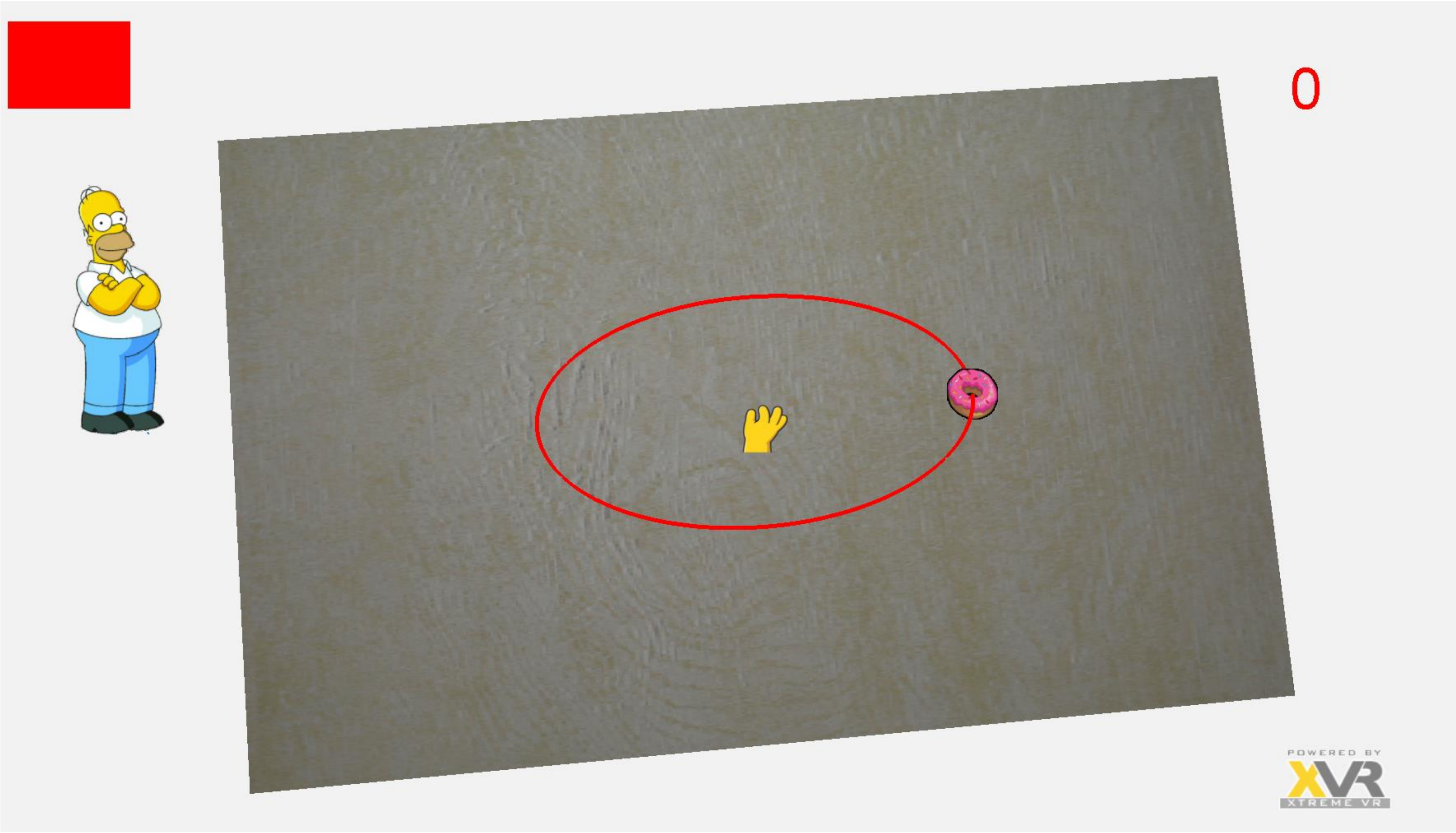
Reaching/grasping tasks

- Reach a target
- No trajectory
- No time constraints

Trajectory driven tasks

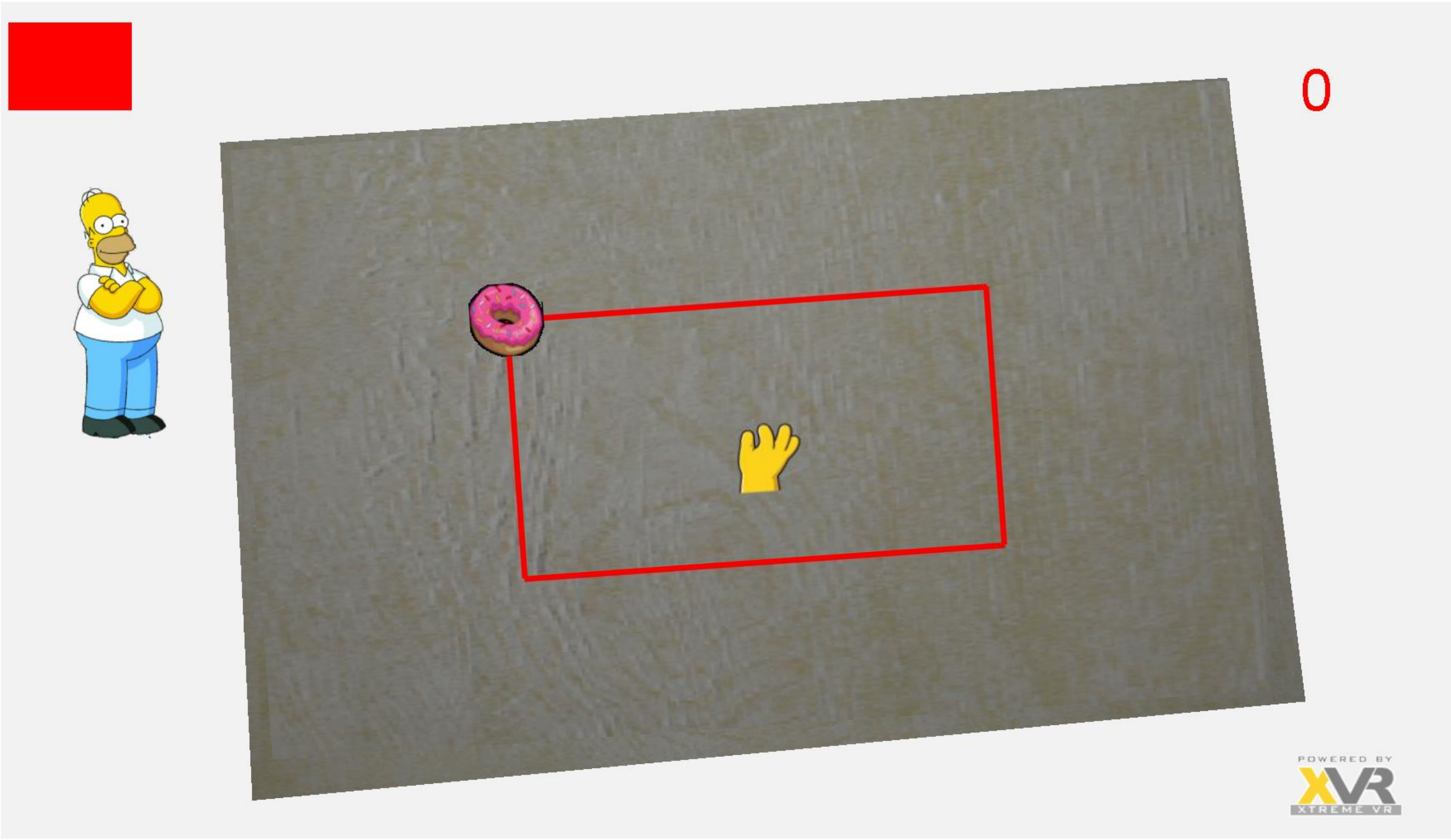


Serious game: PURSUIT



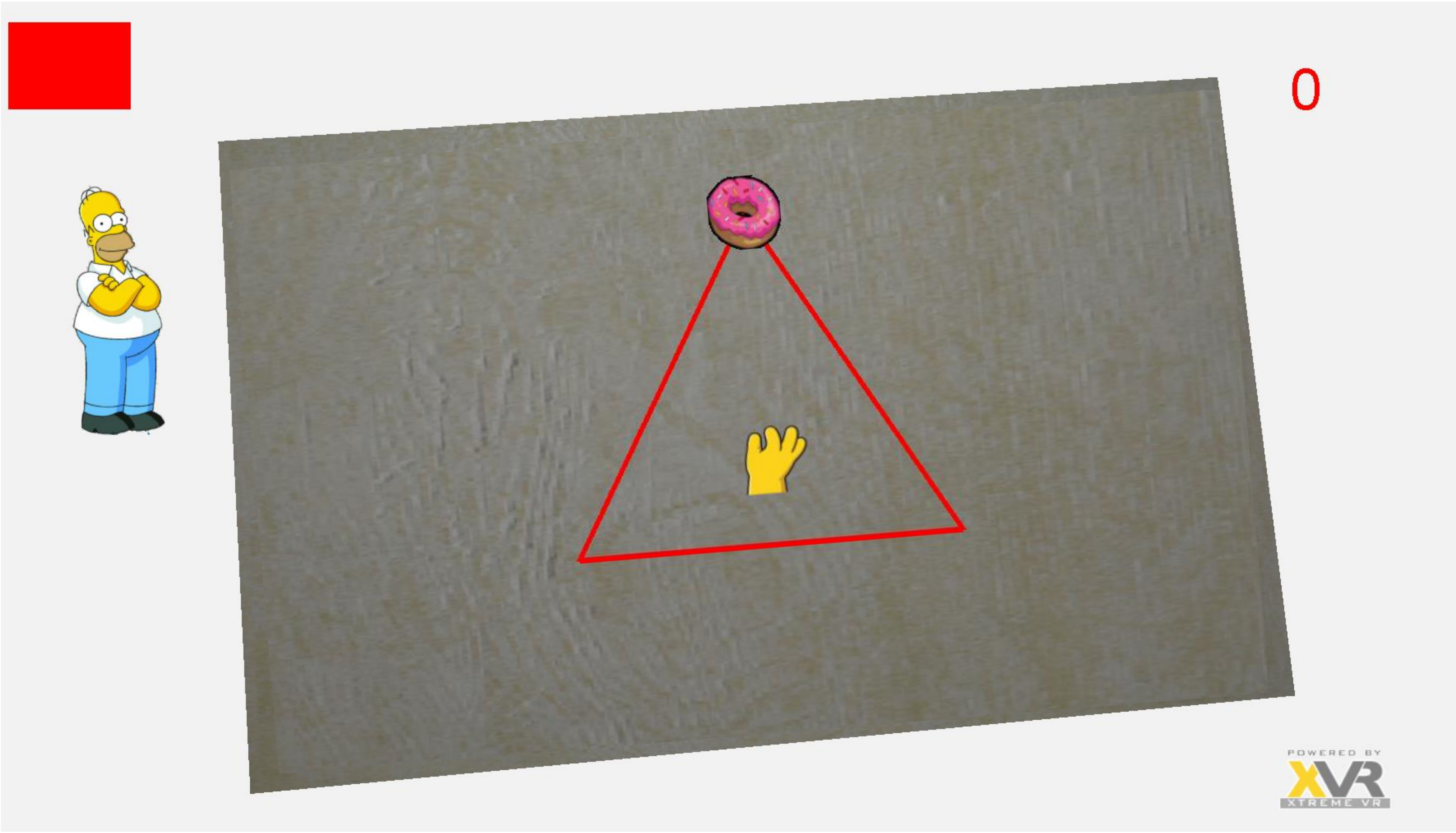
- Stroppa et all, ICNR 2016
- Stroppa et all, ICORR 2017
- Stroppa et all, EuroHaptics 2018

Serious game: PURSUIT



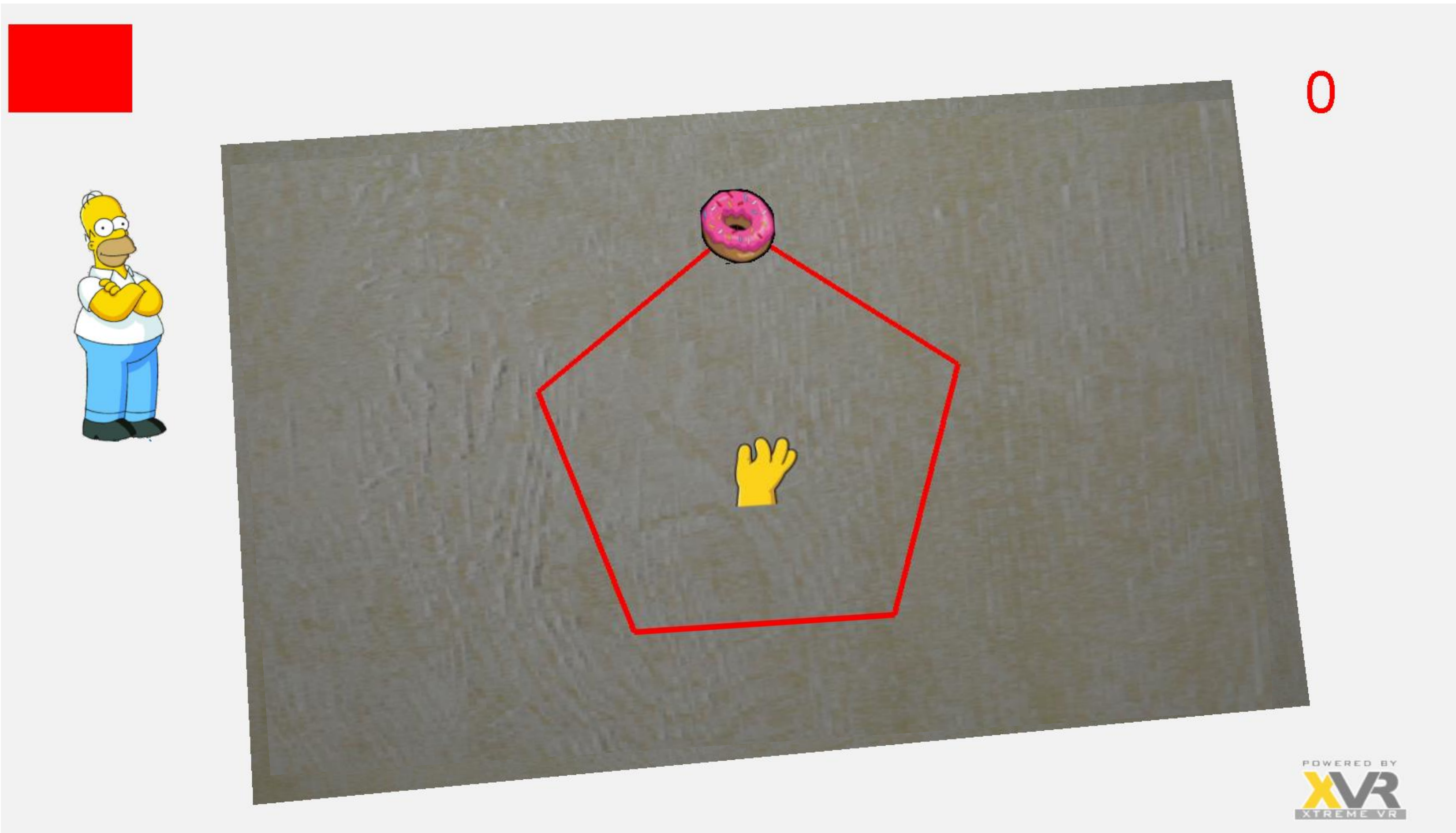
- Stroppa et all, ICNR 2016
- Stroppa et all, ICORR 2017
- Stroppa et all, EuroHaptics 2018

Serious game: PURSUIT



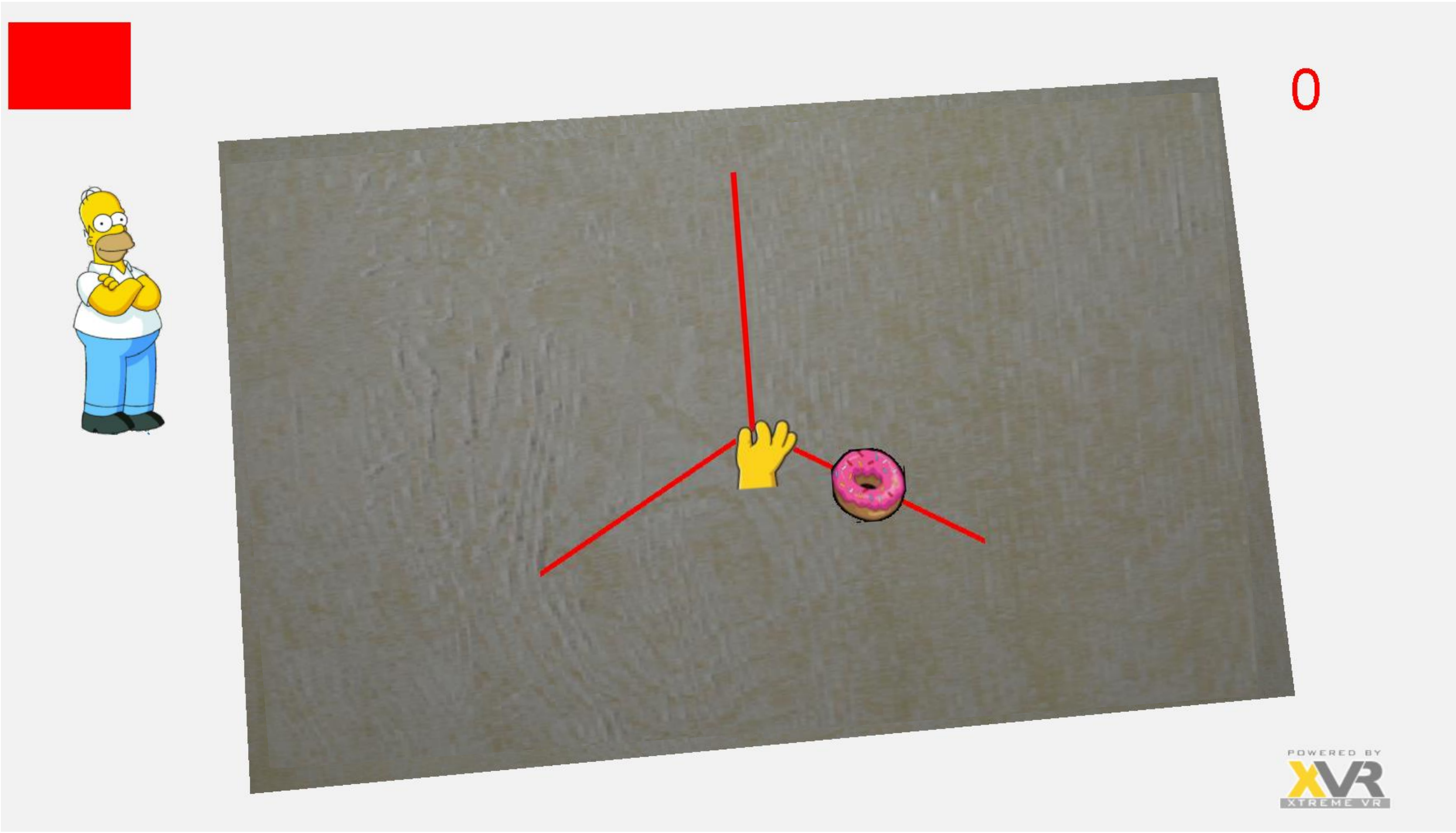
- Stroppa et all, ICNR 2016
- Stroppa et all, ICORR 2017
- Stroppa et all, EuroHaptics 2018

Serious game: PURSUIT



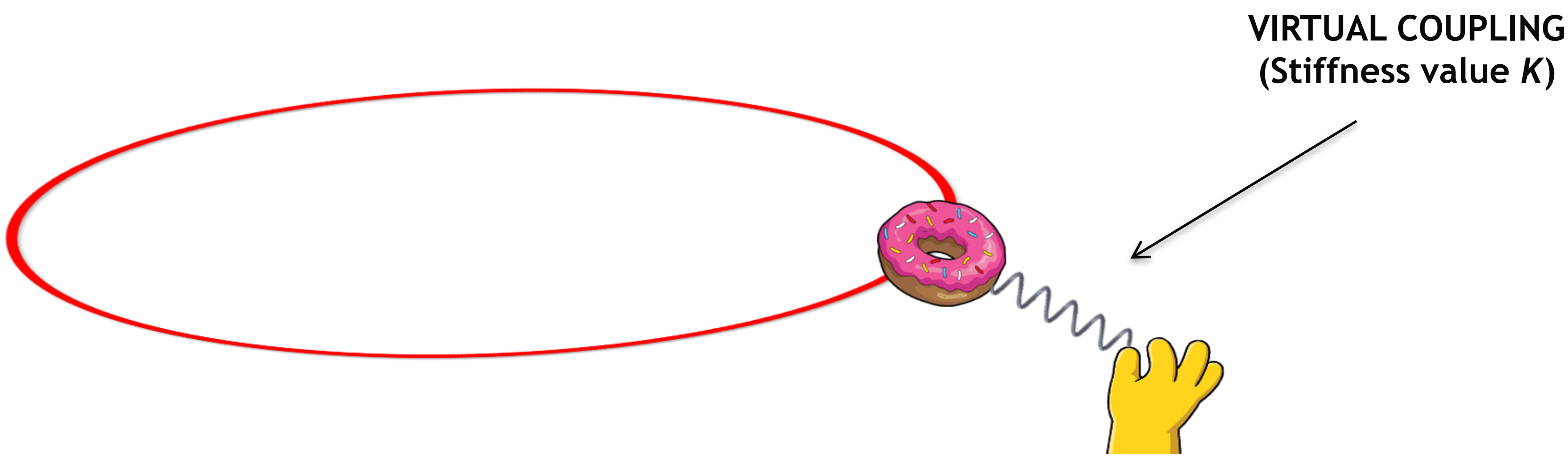
- Stroppa et all, ICNR 2016
- Stroppa et all, ICORR 2017
- [redacted]

Serious game: PURSUIT



- Stroppa et all, ICNR 2016
- Stroppa et all, ICORR 2017
- Stroppa et all, EuroHaptics 2018

Assist-as-needed

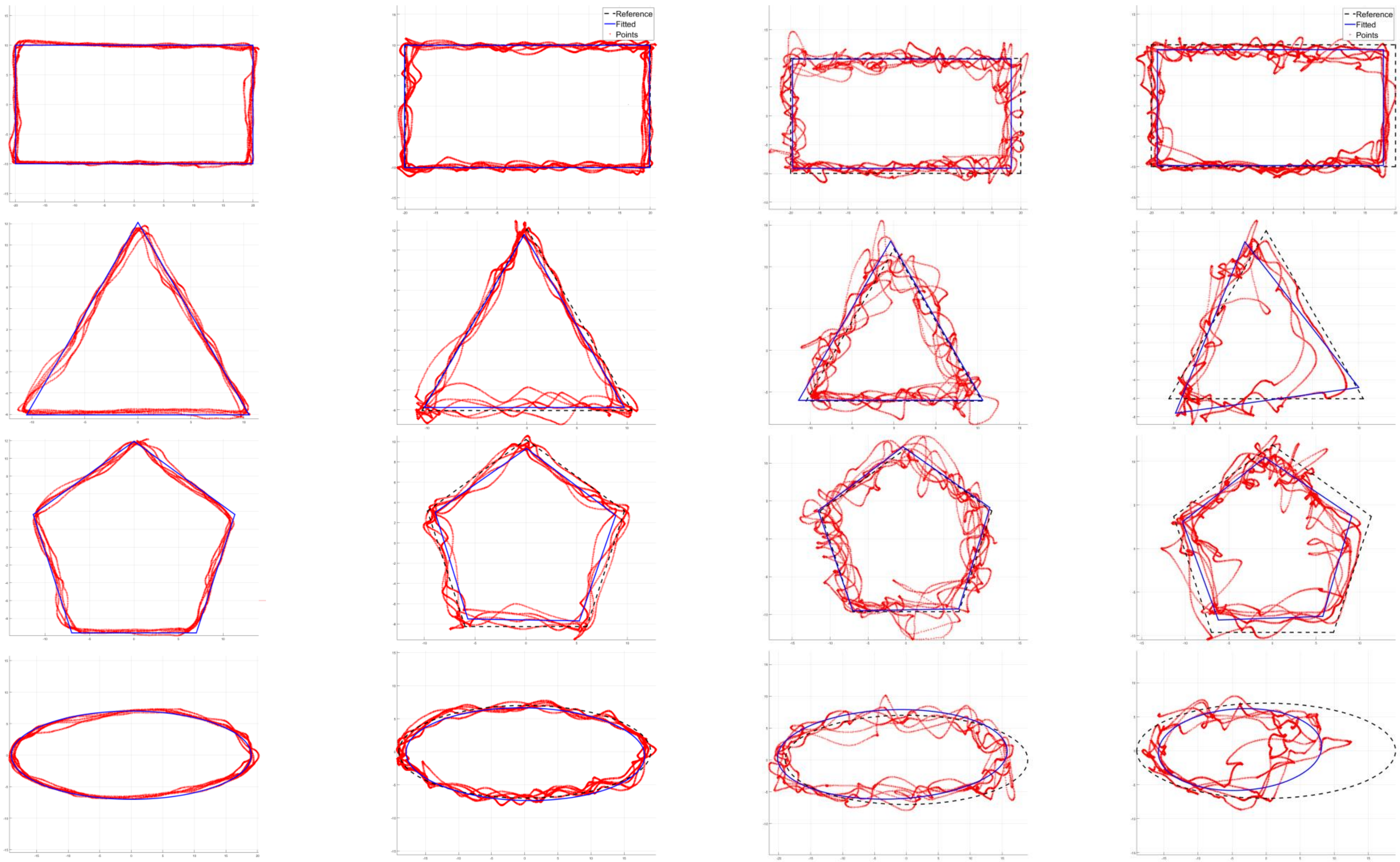


- Stroppa et all, ICNR 2016
- Stroppa et all, ICORR 2017
- Stroppa et all, EuroHaptics 2018

Result comparison

20 HEALTHY SUBJECTS

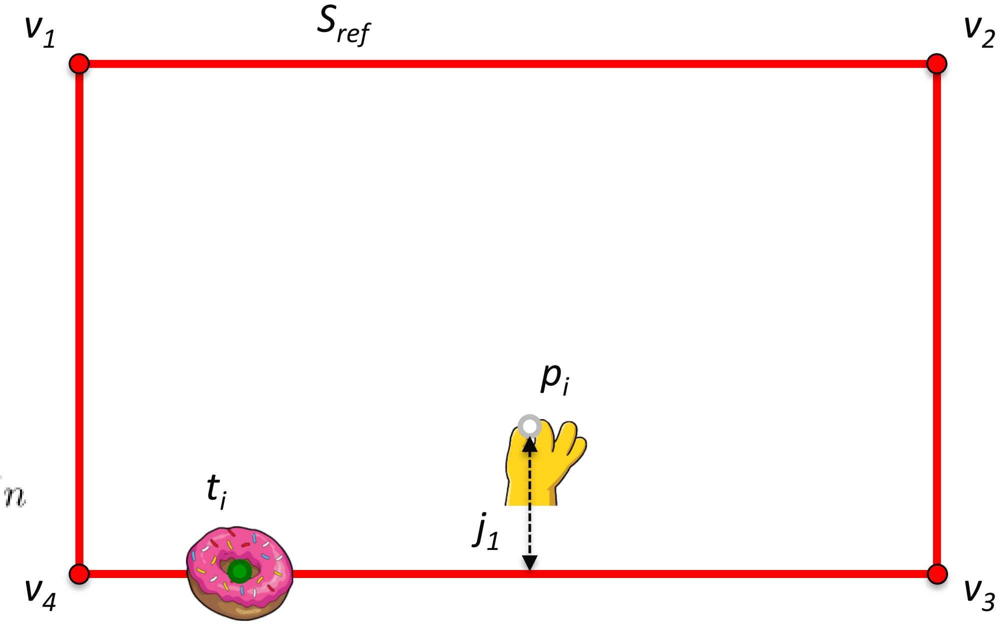
3 STROKE SURVIVORS



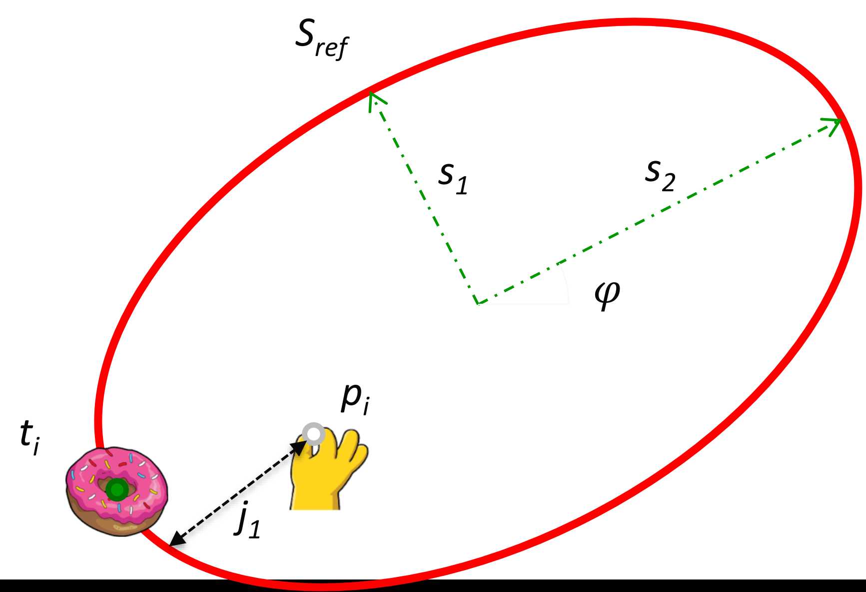
❑ Stroppa et all, Elsevier Applied Soft Computing 2018

Performance indices

$$
\begin{cases}
j_1 = (\sum_{i=1}^{n} \texttt{VoronoiMetrics}(p_i, V))/n \\
j_1 = (\sum_{i=1}^{n} \texttt{PolarMetrics}(p_i, V))/n \\
j_1 = (\sum_{i=1}^{n} \texttt{RadialMetrics}(p_i, \langle s_1, s_2, \varphi \rangle))/n
\end{cases}
$$

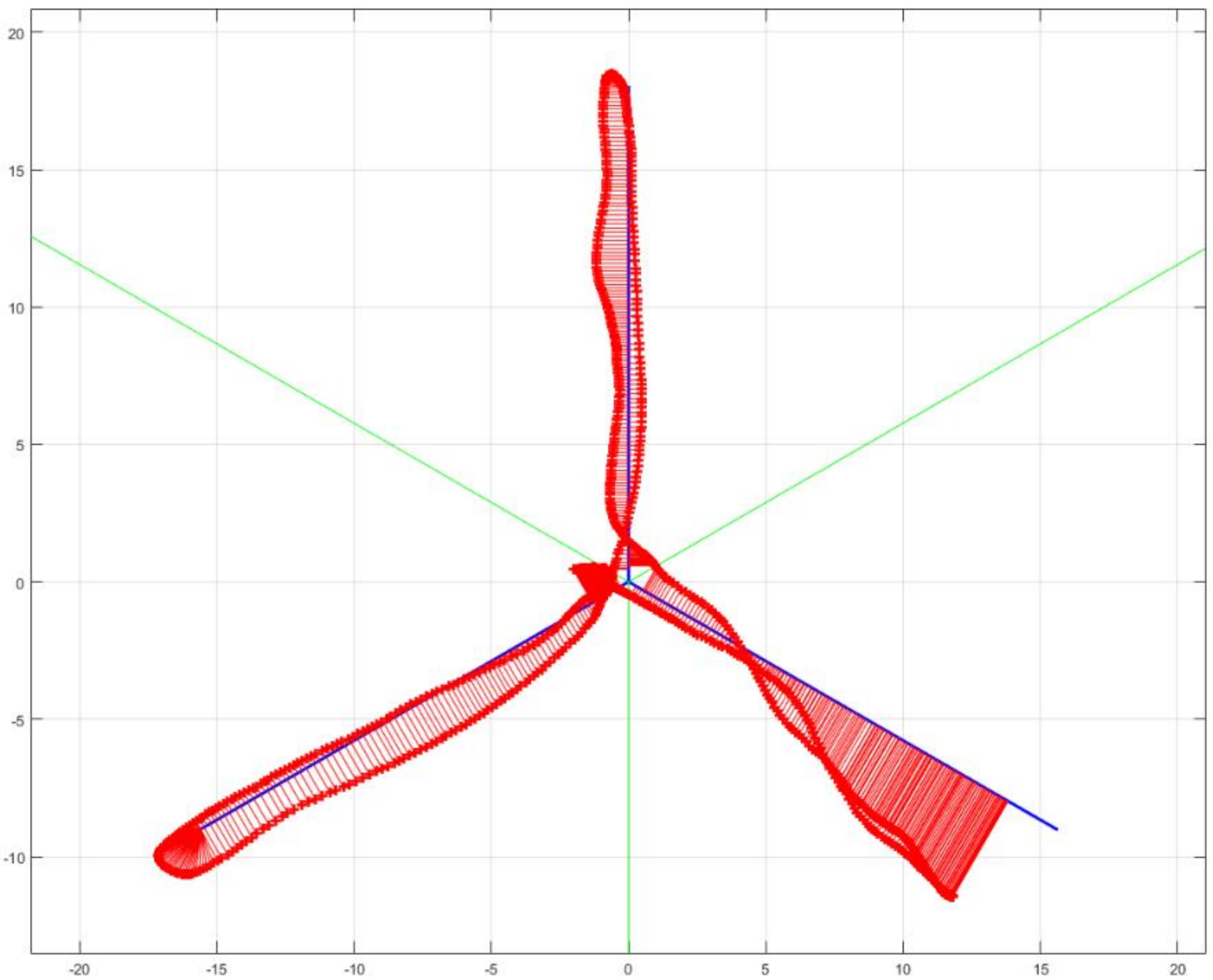


$$j_2 = (\sum_{i=1}^{n} \sqrt{(p_i - t_i)^2})/n$$



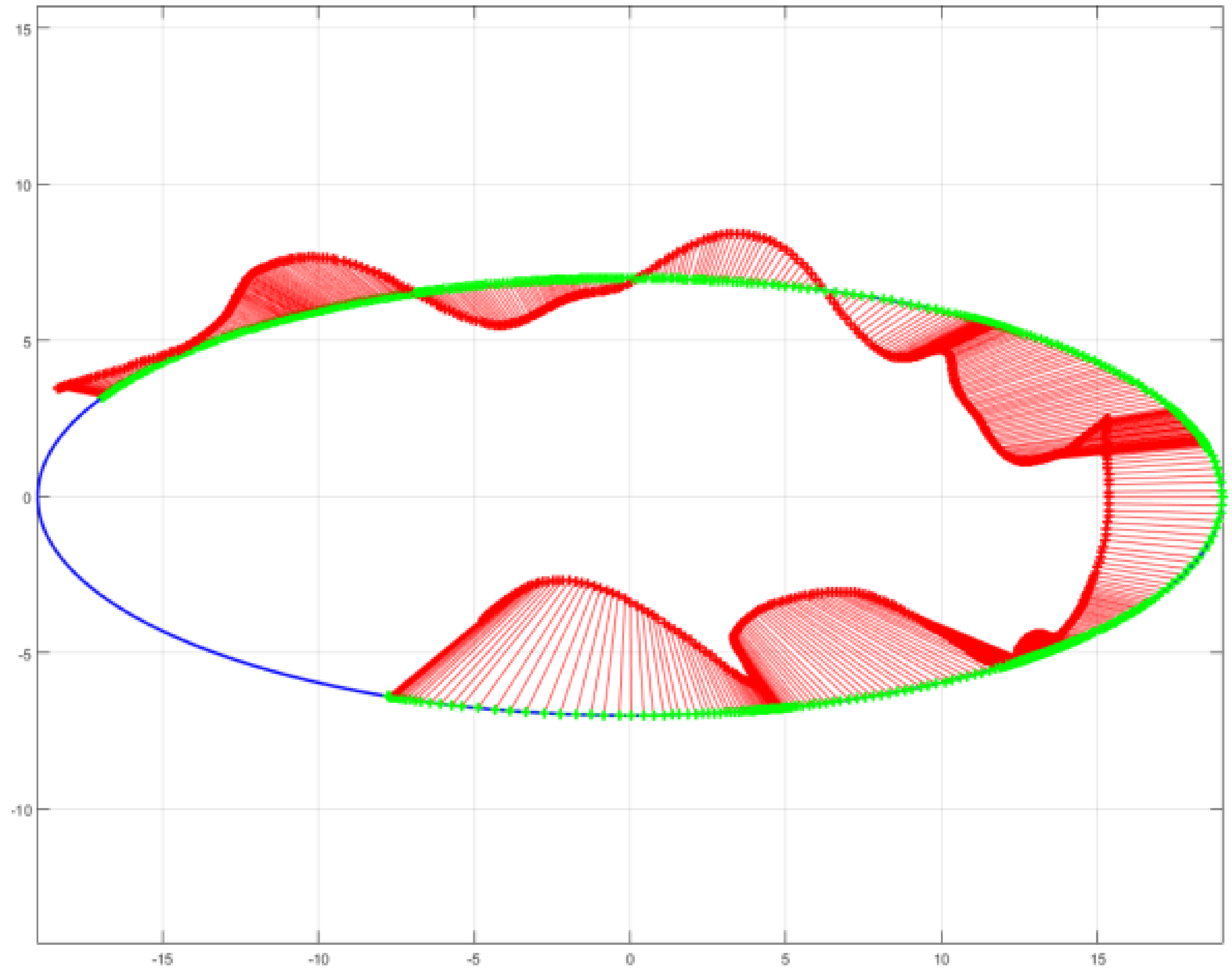
❑ Stroppa et all. EuroHaptics 2018

Example of distance evaluation - Polylines



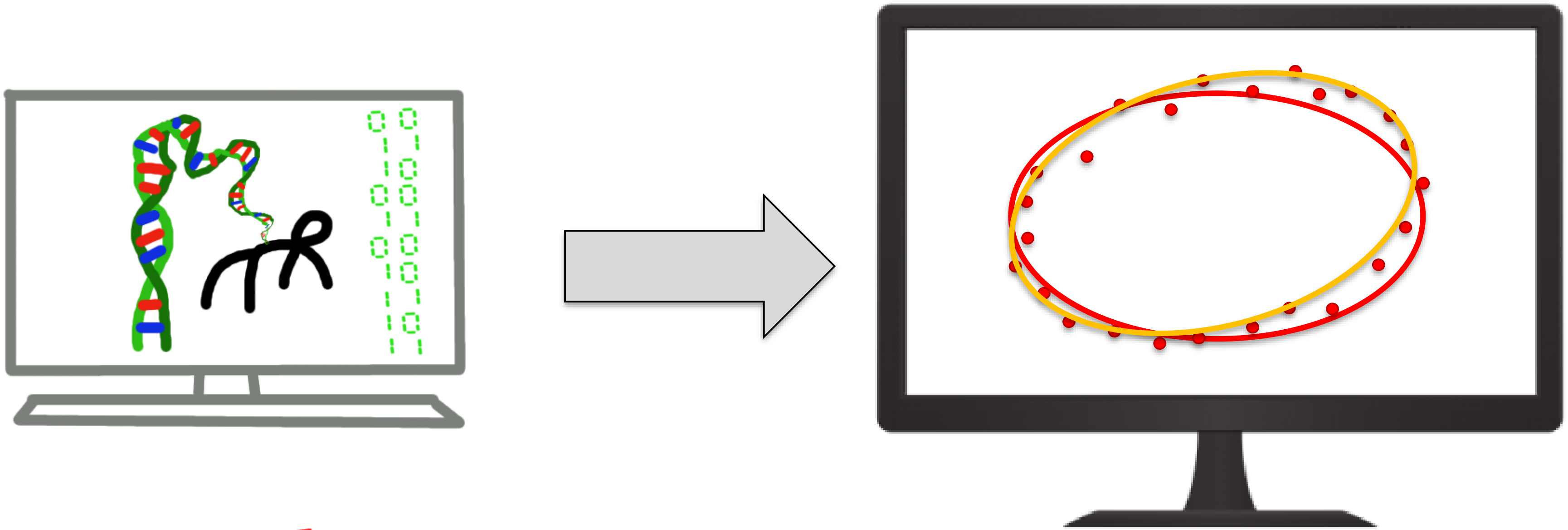
❑ [redacted]

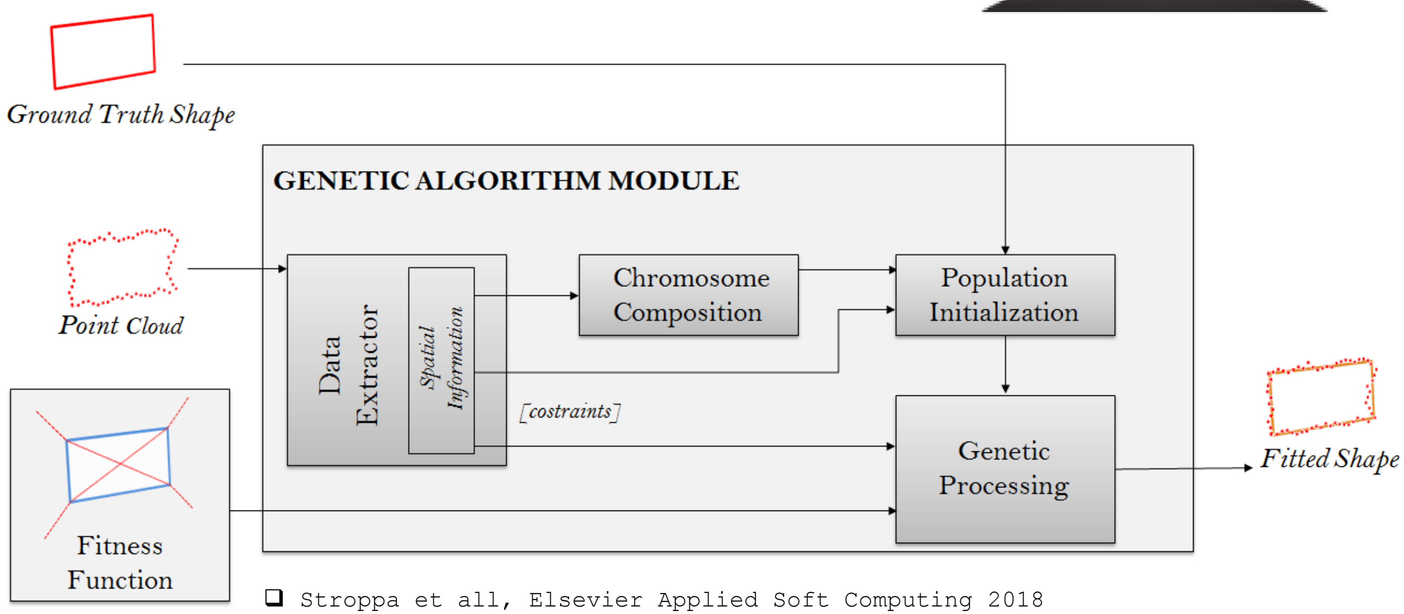
Example of distance evaluation - Ellipses and curves



- Stroppa et all, EasyChair Preprint 2018

Genetic algorithm for shape fitting

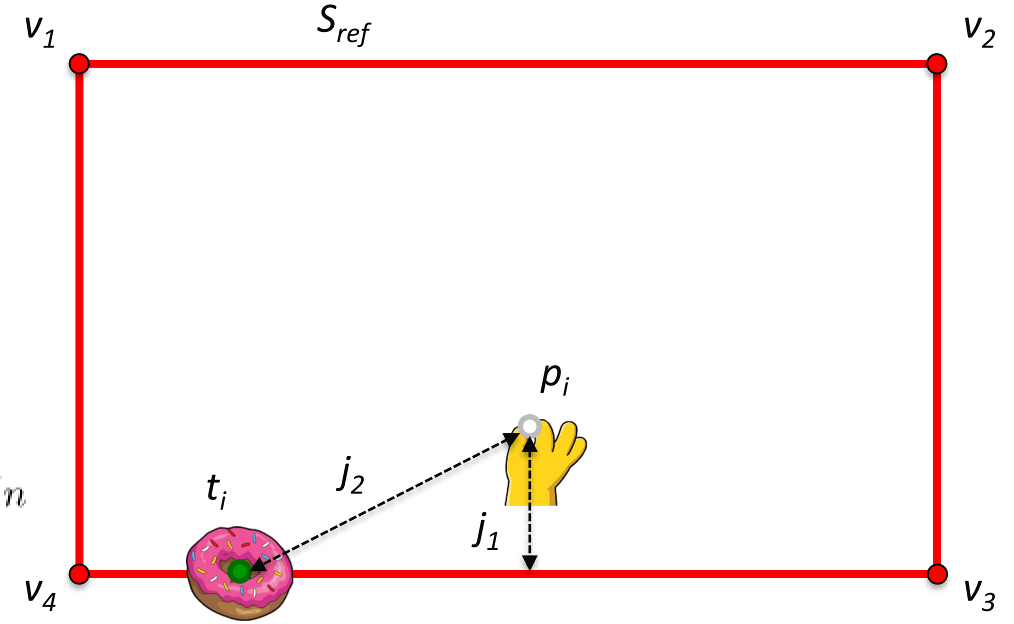




- Stroppa et all, Elsevier Applied Soft Computing 2018

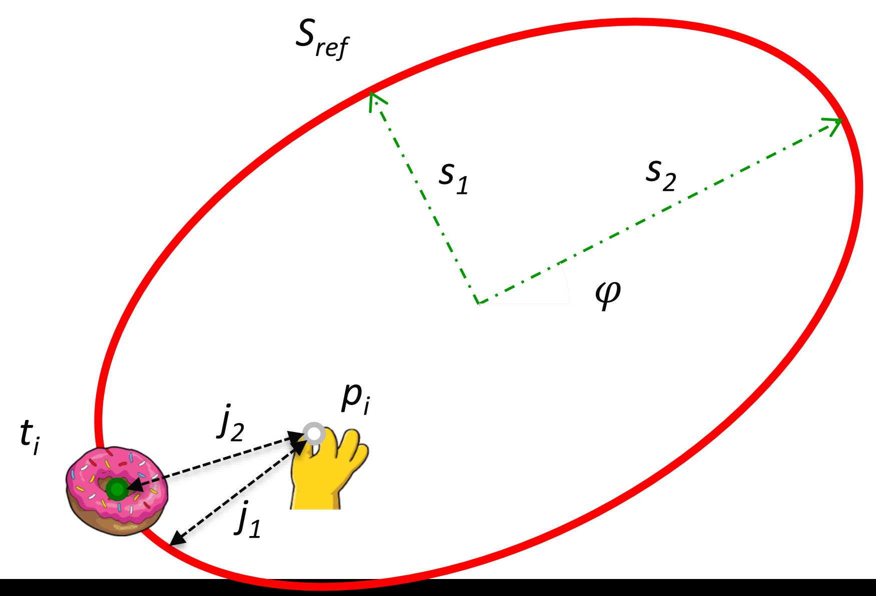
Performance indices

$$\begin{cases} j_1 = (\sum_{i=1}^{n} \texttt{VoronoiMetrics}(p_i, V))/n \\ j_1 = (\sum_{i=1}^{n} \texttt{PolarMetrics}(p_i, V))/n \\ j_1 = (\sum_{i=1}^{n} \texttt{RadialMetrics}(p_i, \langle s_1, s_2, \varphi \rangle))/n \end{cases}$$



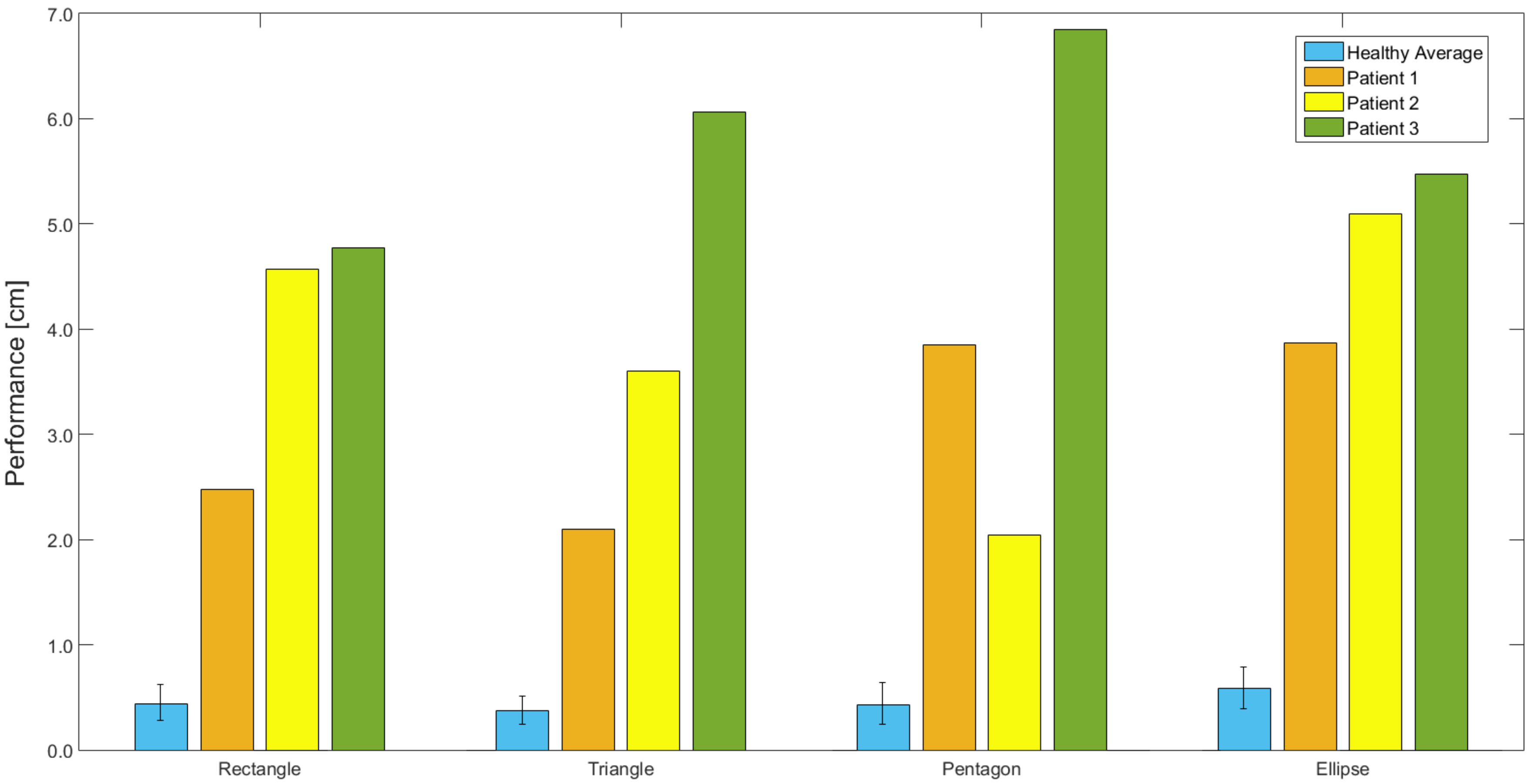
$$j_2 = (\sum_{i=1}^{n} \sqrt{(p_i - t_i)^2})/n$$

$$j = \frac{j_1 + j_2}{2}$$



- Stroppa et all, EuroHaptics 2018

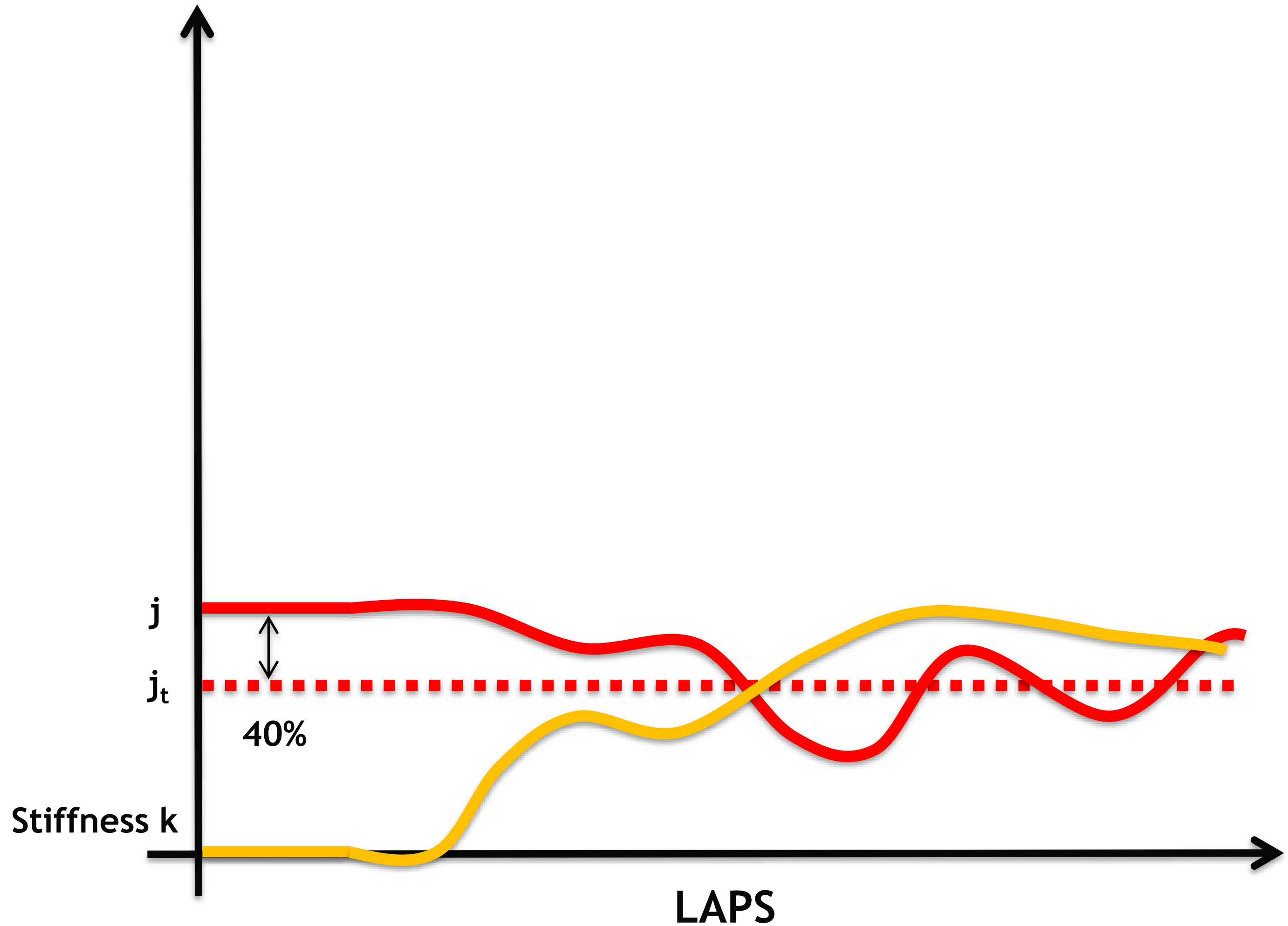
Result comparison



- Stroppa et all, Elsevier Applied Soft Computing 2018

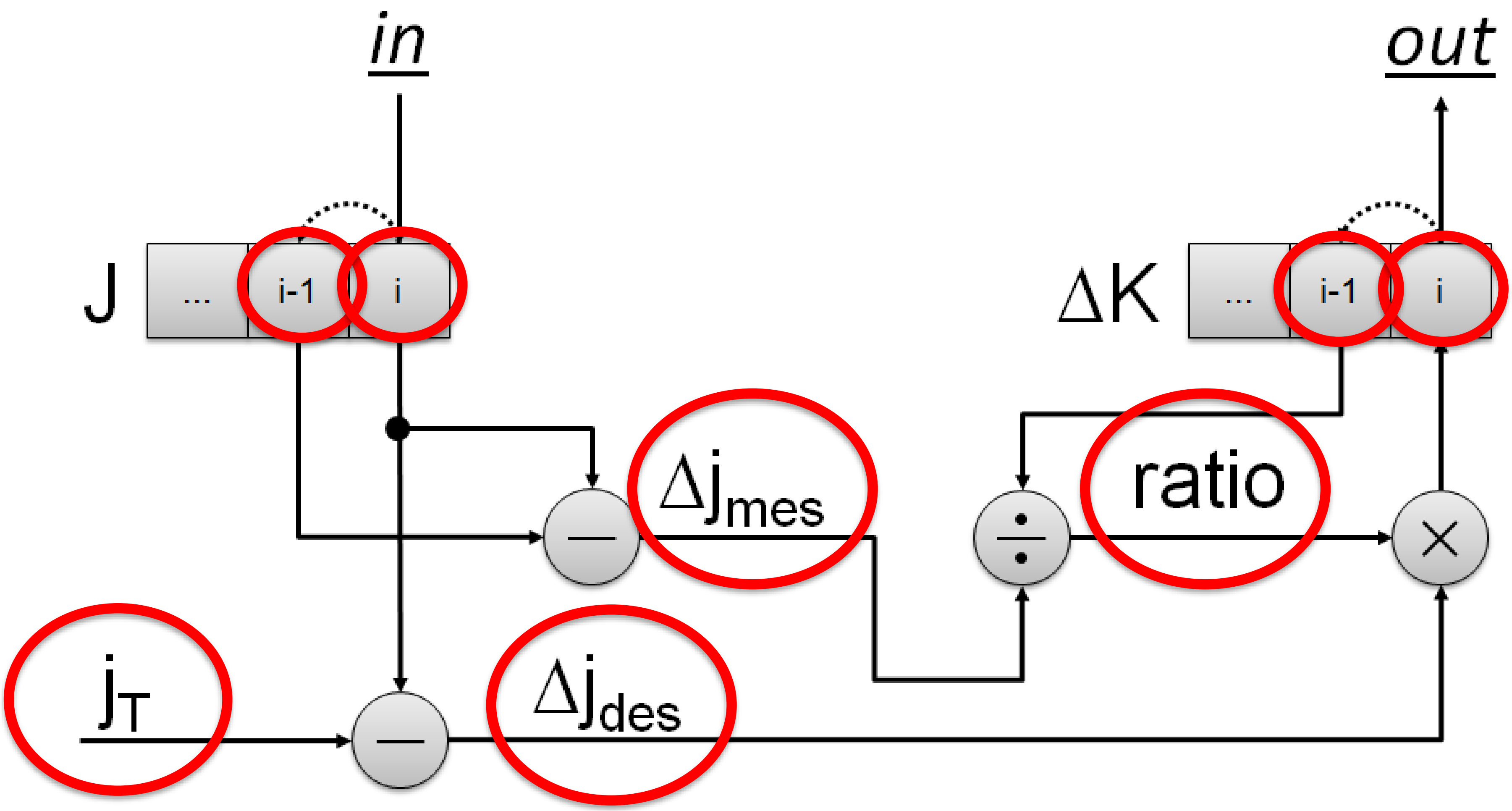
Assistance tuning

$$j = \frac{j_1 + j_2}{2}$$



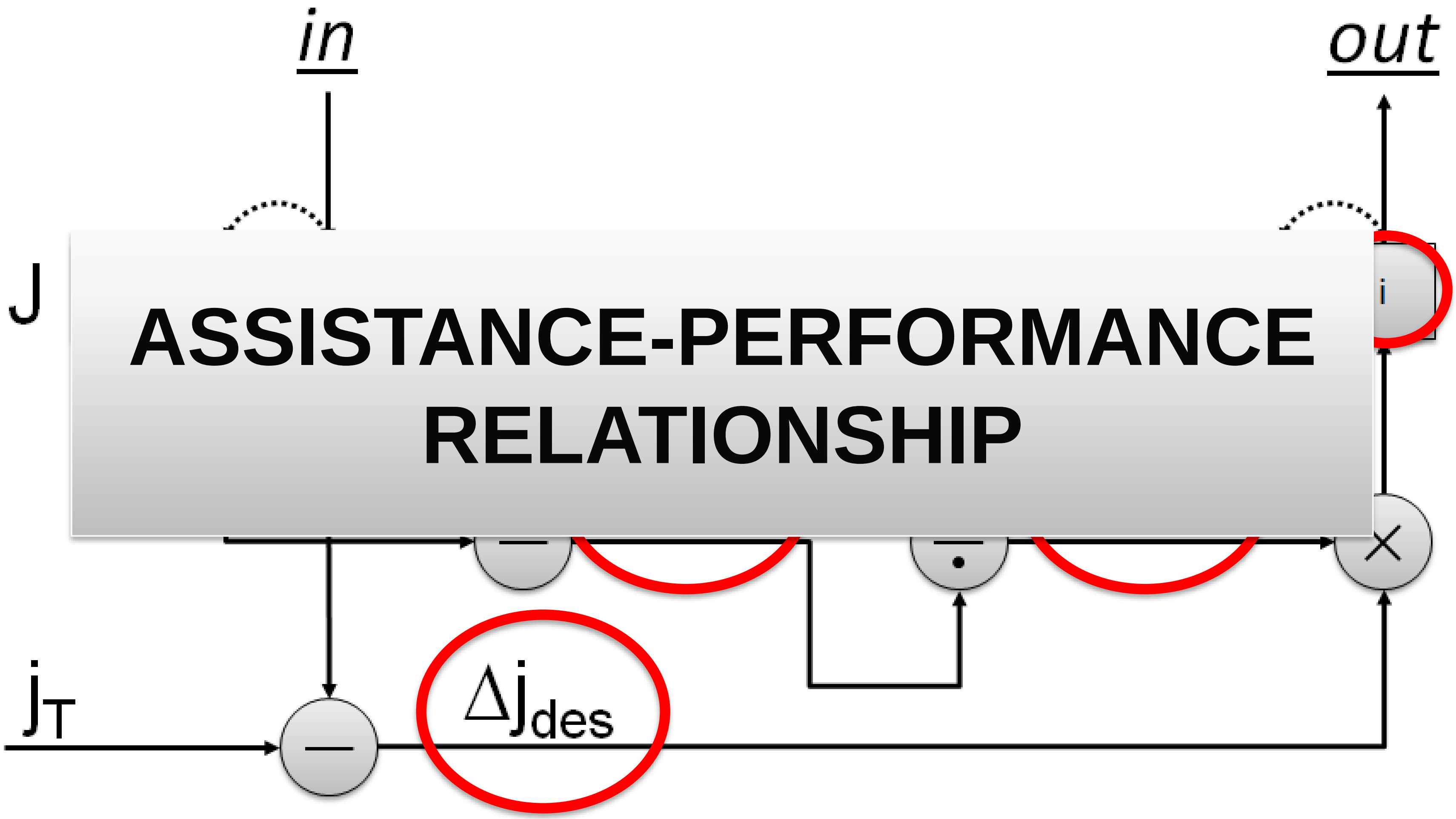
- Stroppa et all, ICORR 2017
- [redacted]

Control scheme



❑ Stroppa et all, EuroHaptics 2018

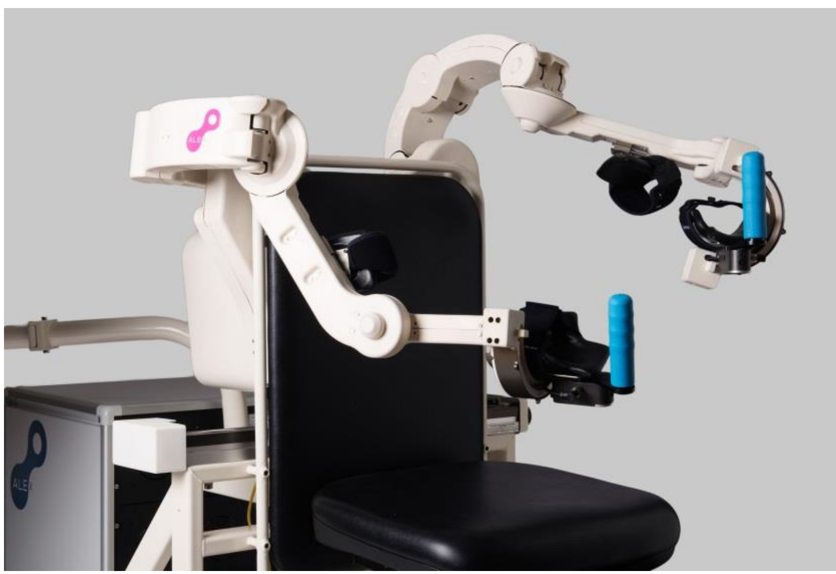
Control scheme



ASSISTANCE-PERFORMANCE RELATIONSHIP

- Stroppa et all, EuroHaptics 2018

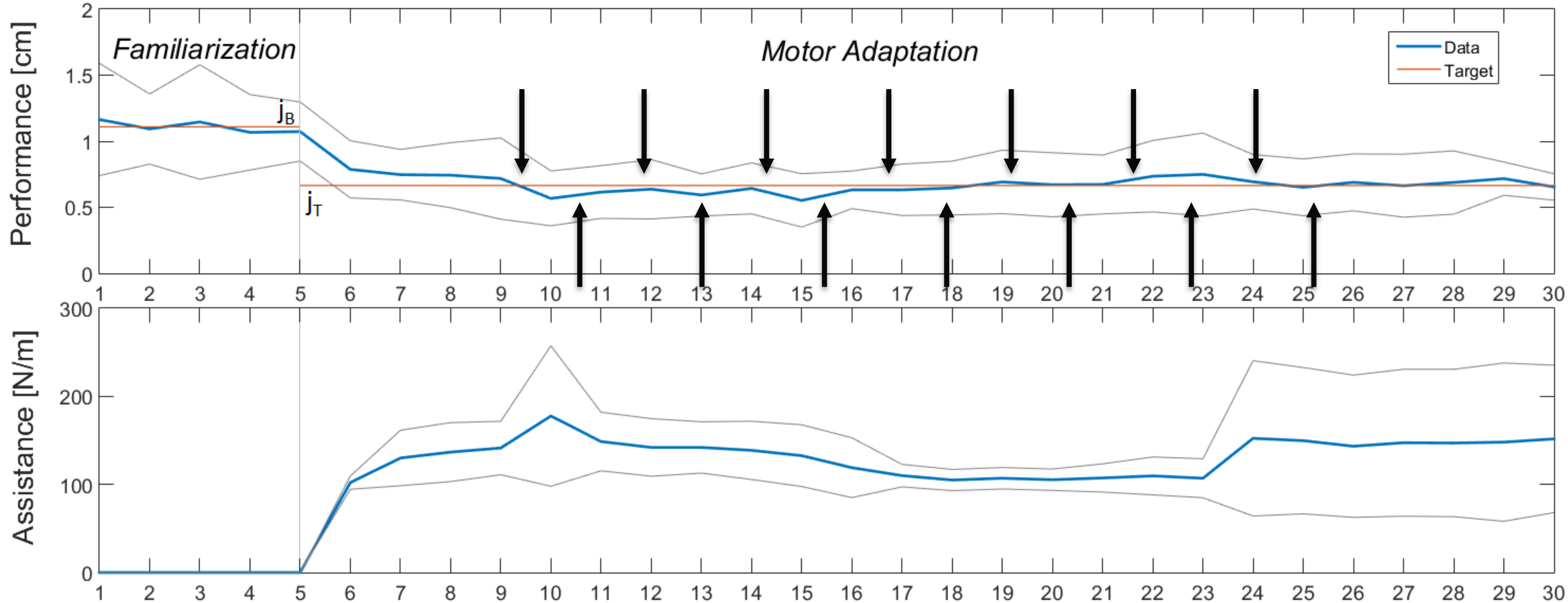
ALEx Rehab Station



- Pirondini et all, Journal of Neuroengineering and Rehabilitation 2016
- Stroppa et all, ICORR 2017

Validation with healthy subjects

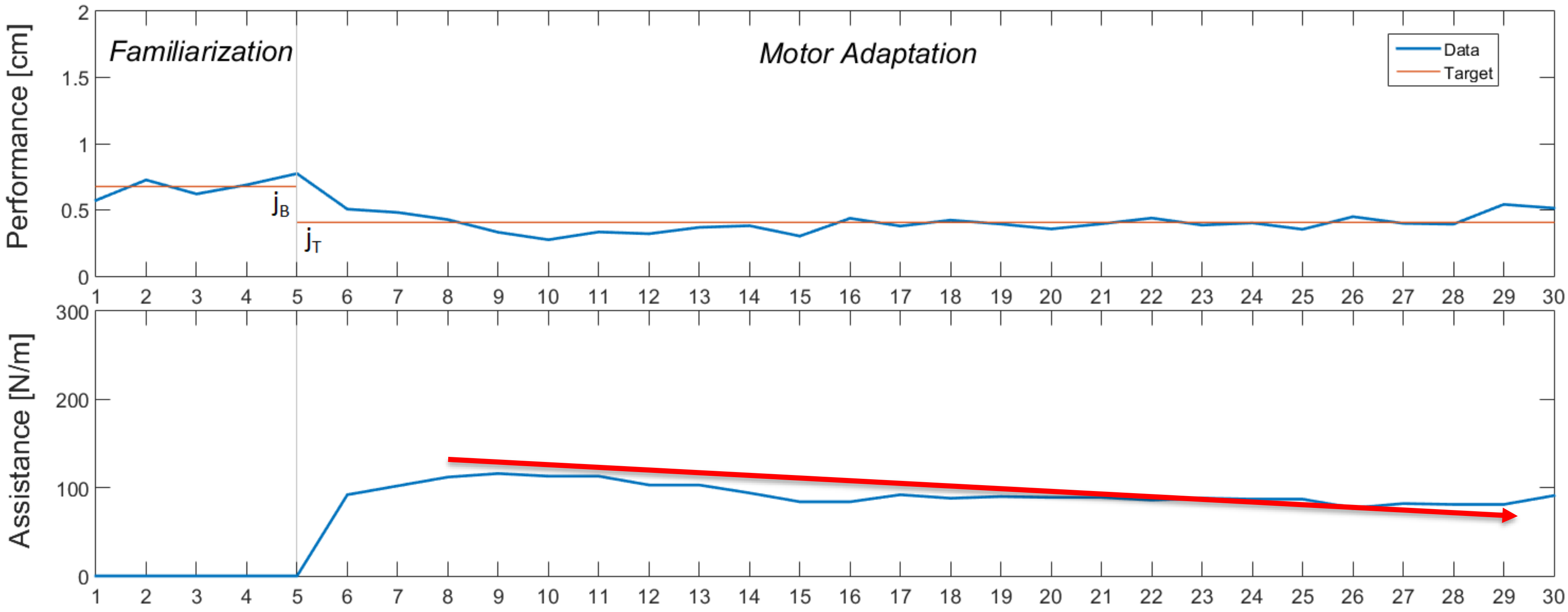
Average on fifteen subjects



❑ Stroppa et all, EuroHaptics 2018

Validation with healthy subjects

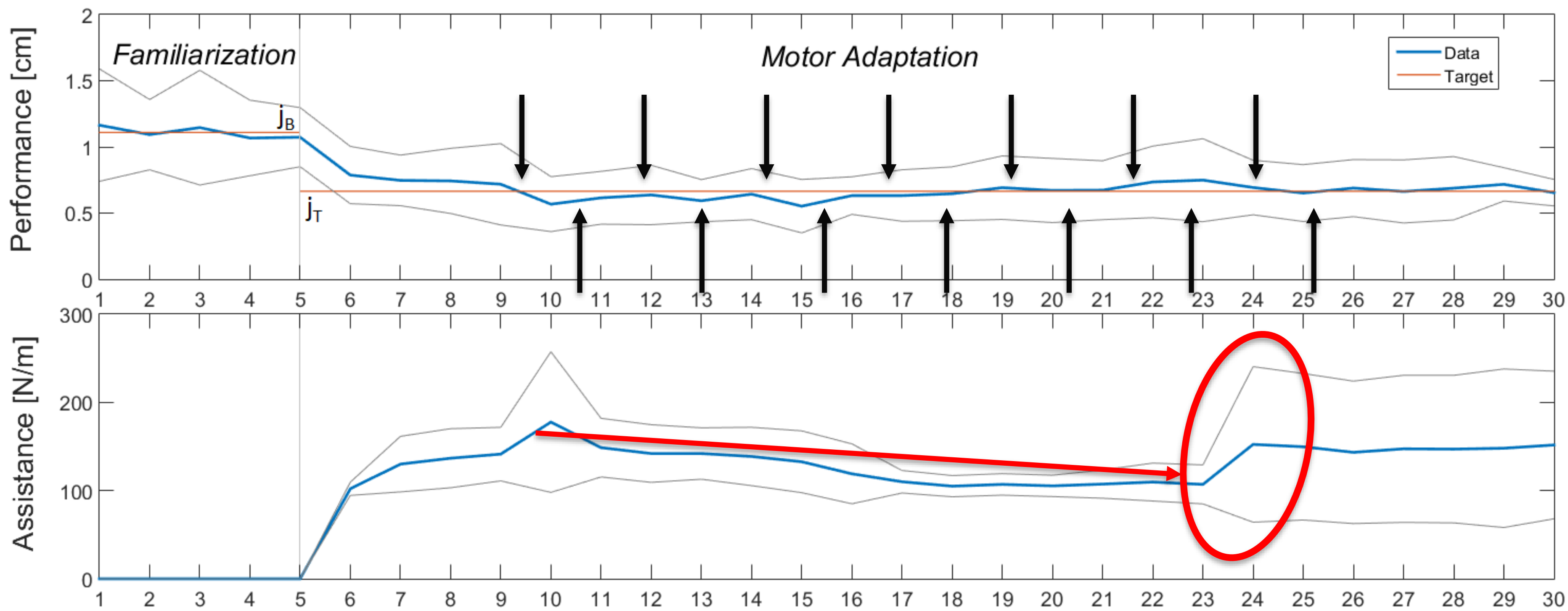
One single subject



- Squeri et all, ICORR 2011
- Stroppa et all, EuroHaptics 2018

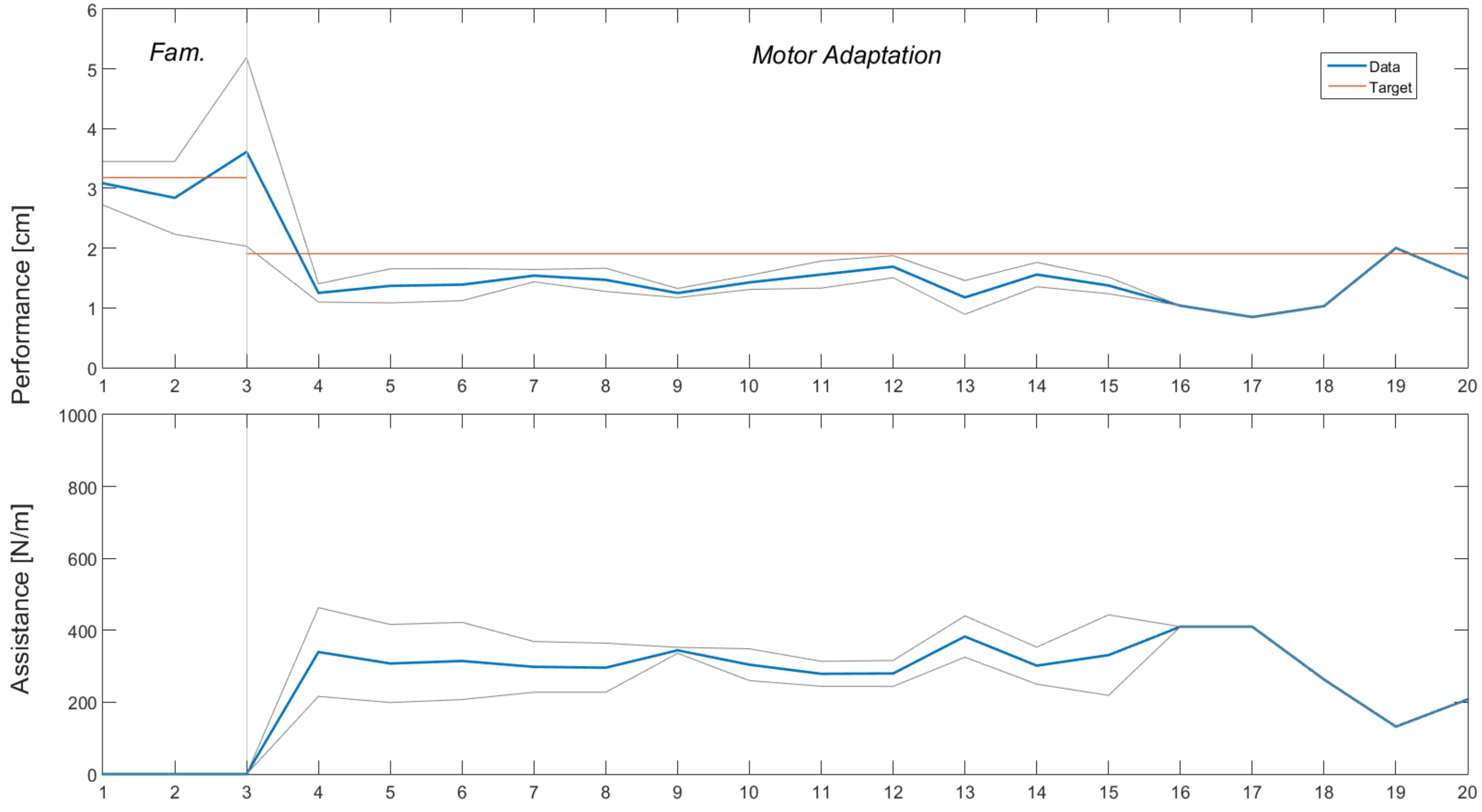
Validation with healthy subjects

Average on fifteen subjects

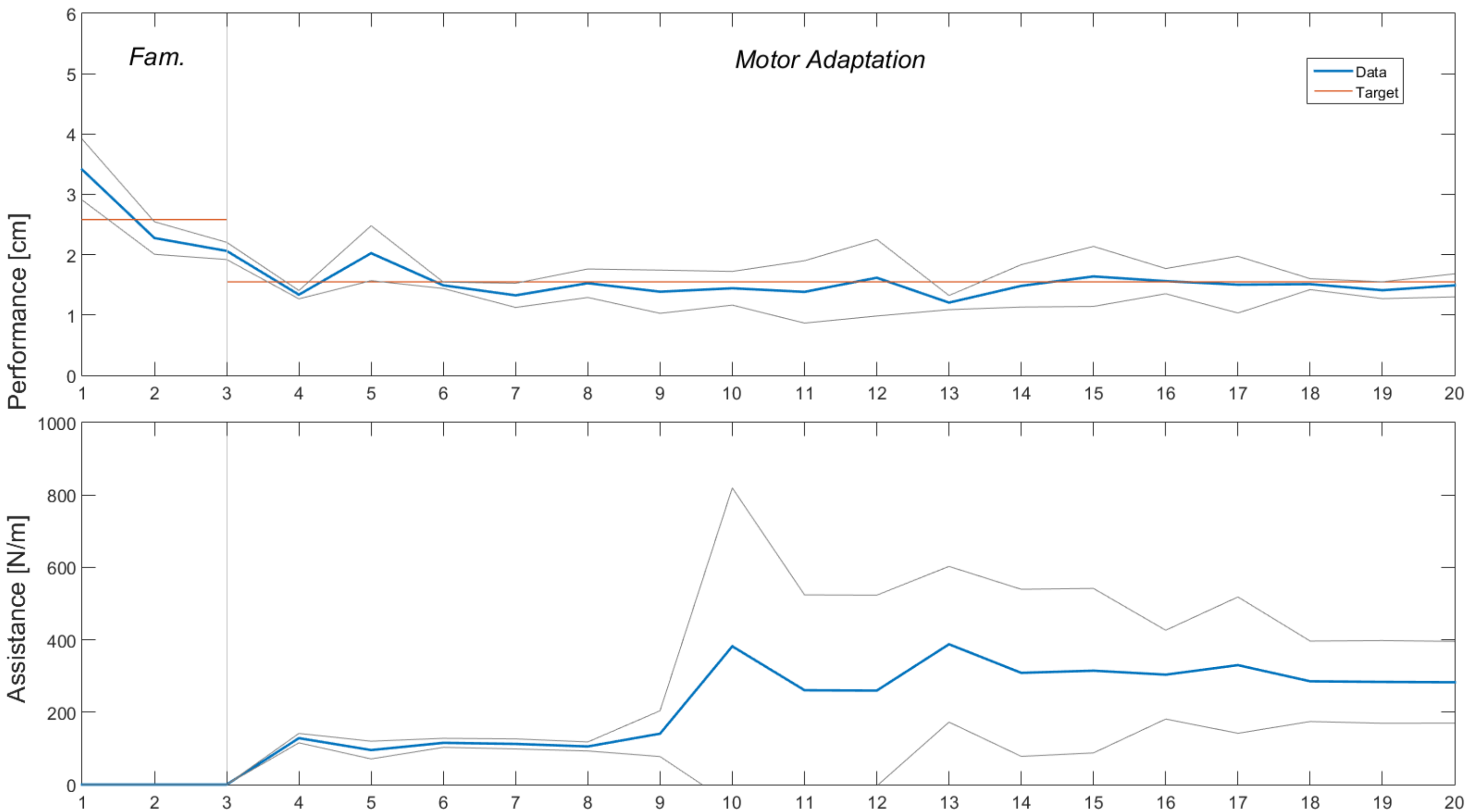


❑ Stroppa et all, EuroHaptics 2018

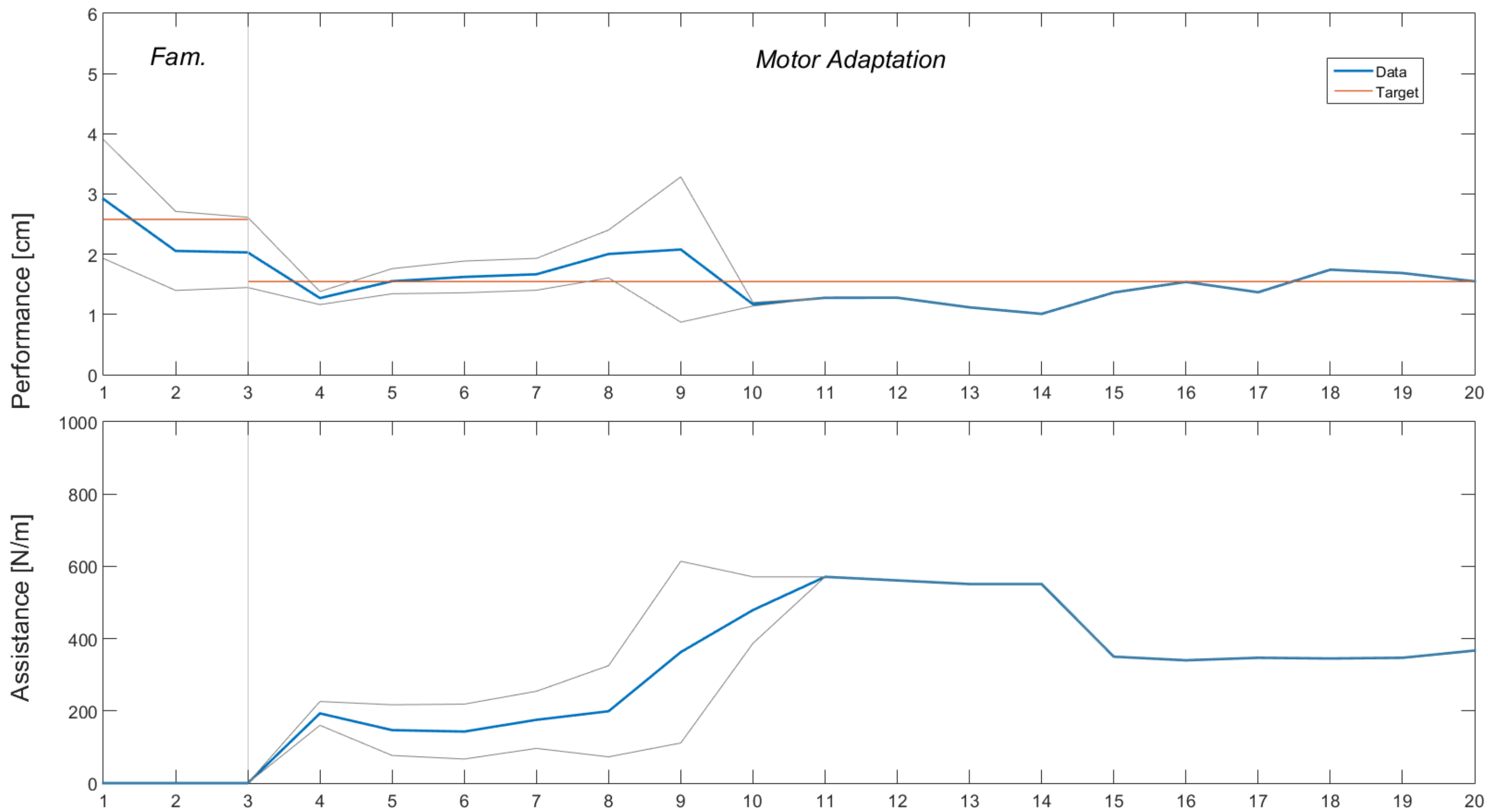
Trial with a single post-stroke survivor



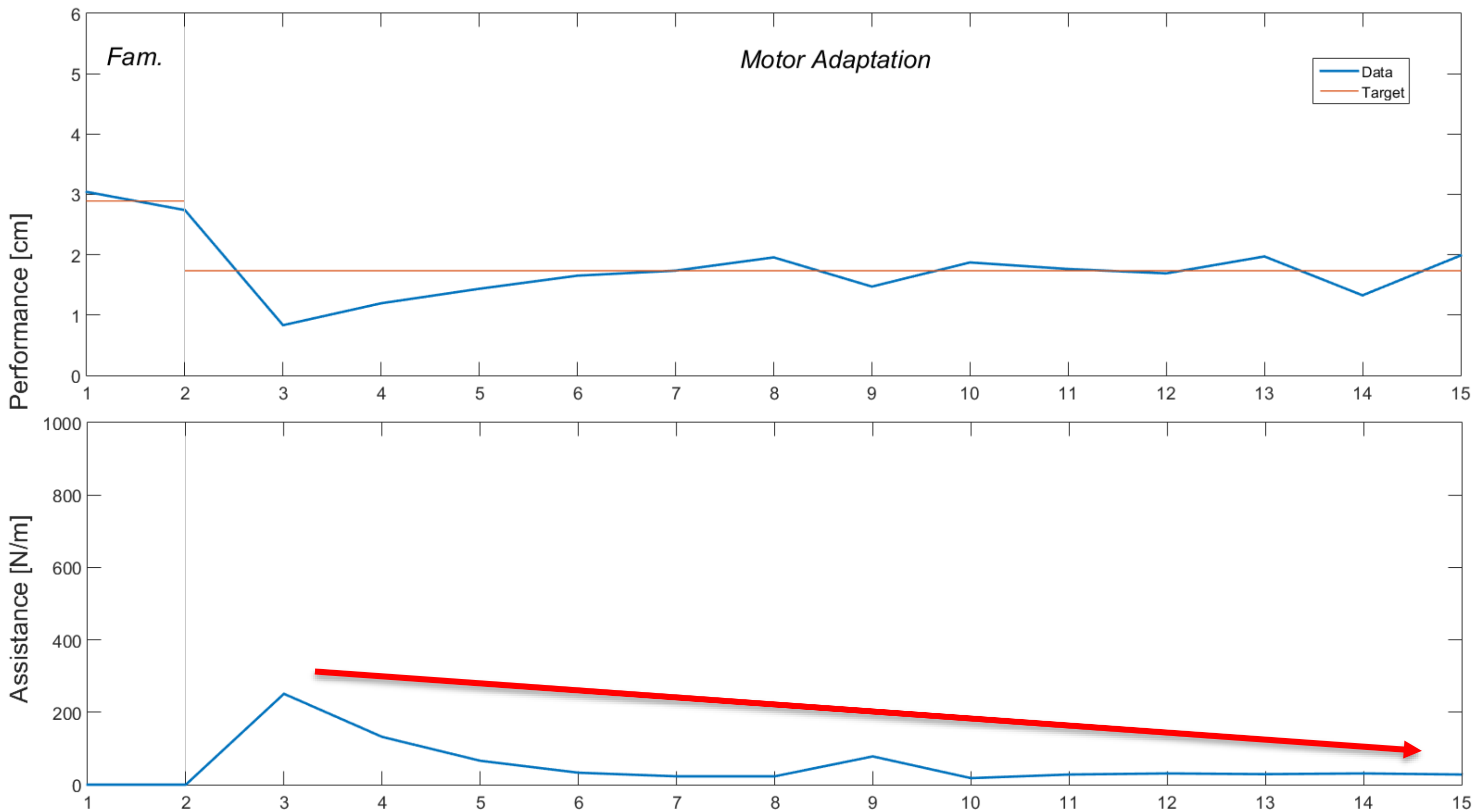
Trial with a single post-stroke survivor



Trial with a single post-stroke survivor



Trial with a single post-stroke survivor



thank you!

email: a.frisoli@sssup.it