Politecnico di Bari
May 21, 2019

Robotics and technologies for Rehabilitation and Sports Medicine

Stefano Mazzoleni, PhD
The BioRobotics Institute, Scuola Superiore Sant’Anna
Head, Bioengineering Rehabilitation Lab
IEEE RAS Technical Committee on Rehabilitation and Assistive Robotics

Outline of the presentation

- BioRobotics and Bionics convergence
- Rehabilitation and Assistive Robotics
  - Upper limb robot-assisted therapy
  - Gait robot-assisted therapy
  - Precision orthopaedic surgery - Precision orthopaedic rehab
  - RISE robotic wheelchair
- Biomechanics for Sports Medicine
- Lessons, new scenarios and challenges

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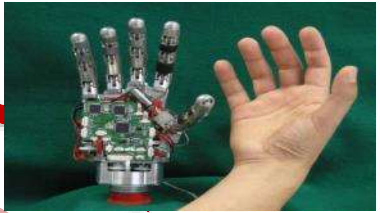
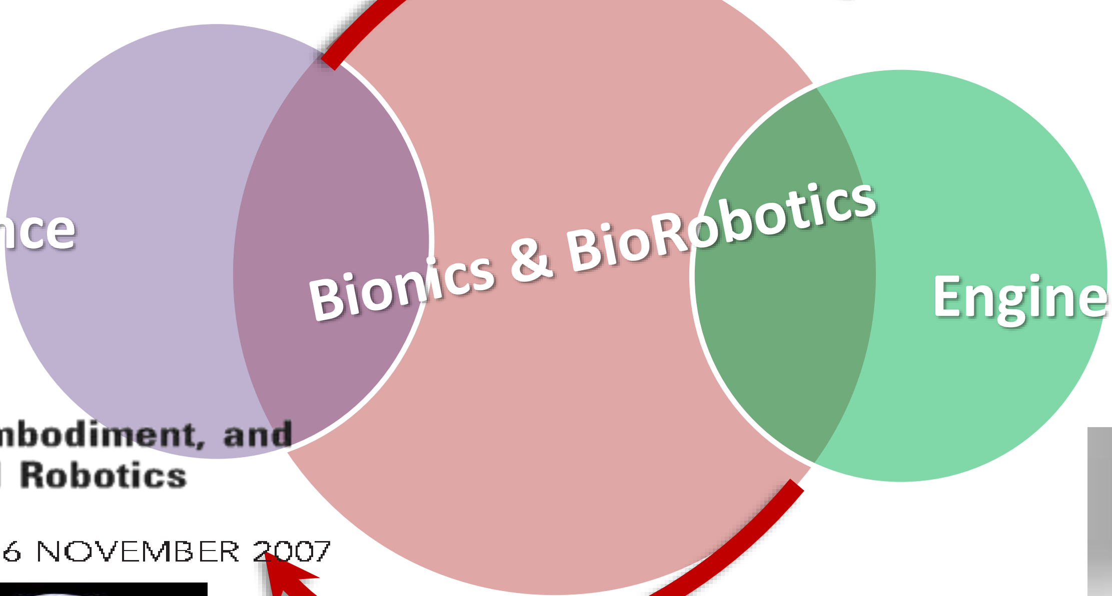
From Swimming to Walking with a Salamander Robot Driven by a Spinal Cord Model

Auke Jan Ijspeert,[1*] Alessandro Crespi,[1] Dimitri Ryczko,[2,3] Jean-Marie Cabelguen[2,3]

9 MARCH 2007 VOL 315 SCIENCE www.sciencemag.org





June 2015

Self-Organization, Embodiment, and Biologically Inspired Robotics

Rolf Pfeifer,[1*] Max Lungarella,[1] Fumiya Iida[1,2]

SCIENCE VOL 318 16 NOVEMBER 2007


nature International weekly journal of science

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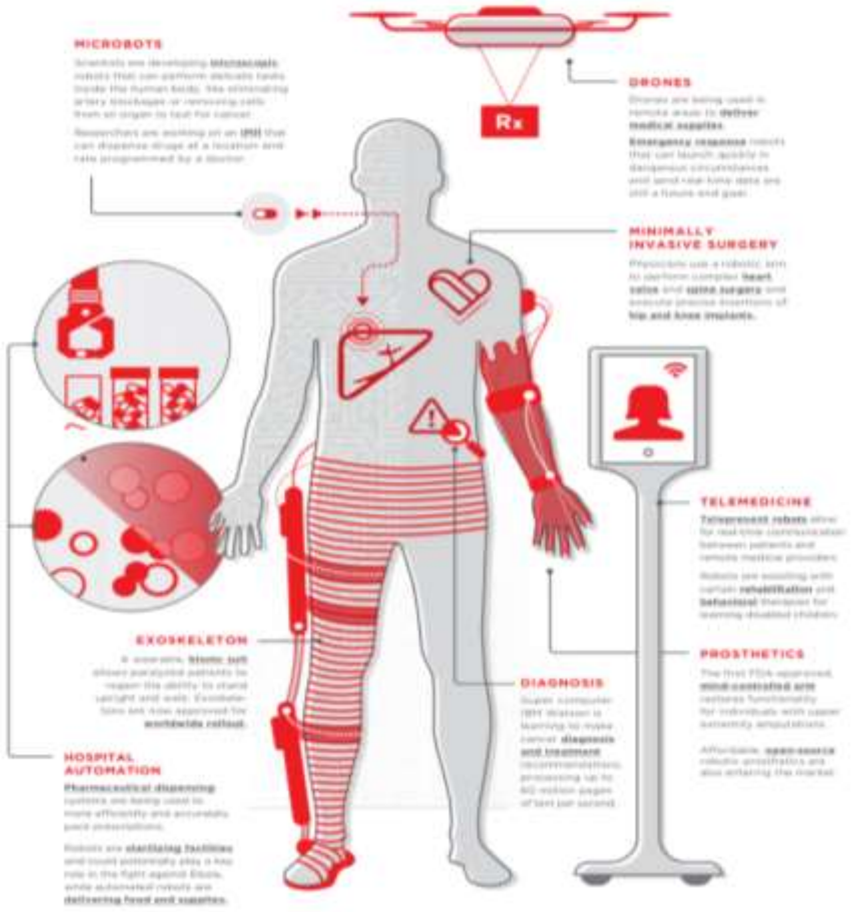
NATURE | NEWS FEATURE

The Pentagon's gamble on brain implants, bionic limbs and combat exoskeletons

DARPA is making a big push into biological research — but some scientists question whether its high-risk approach can work.

Robotics in healthcare



No longer science fiction, robotics has emerged as a leading alternative for many healthcare applications

Dr. Daniel Kraft - "*What's next in healthcare?*"

Daniel Kraft is a physician-scientist, inventor and innovator. He is chair of the Medicine track for Singularity University and Executive Director for FutureMed, a program which explores convergent, exponentially developing technologies and their potential in biomedicine and healthcare

Joint Scuola Superiore Sant'Anna-Auxilium Vitae "Rehabilitation Bioengineering Laboratory"

Founded in 2011, the Scuola Superiore Sant'Anna - Auxilium Vitae Rehabilitation Centre (100 beds) **joint research laboratory** is composed by bioengineers, medical doctors and therapists

Clinical facility

- *Cardio-respiratory Dept:* 42 beds + 8 beds for assisted ventilation, monitoring and weaning
- *Neurological Rehabilitation Unit*: 35 beds
- *Severe Traumatic Brain Injury Rehabilitation Unit*: 15 beds

Research activities

- Design, development and validation of **robotic systems for** neurological rehabilitation (stroke, brain injury)
- **Tele-rehabilitation applications** (continuity of care from hospital to home/residential setting) for neurological and cardio-respiratory rehabilitation
- **E-health solution** for pulmonary rehabilitation (telemonitoring of physiological and respiratory parameters for ventilator-dependent patients)

www.auxiliumvitae.it

Rehabilitation Bioengineering Laboratory

Robotic systems for upper limb motor therapy, technologies for e-health and sports biomechanics

Stefano Mazzoleni

Vi Do Tran

Elena Battini

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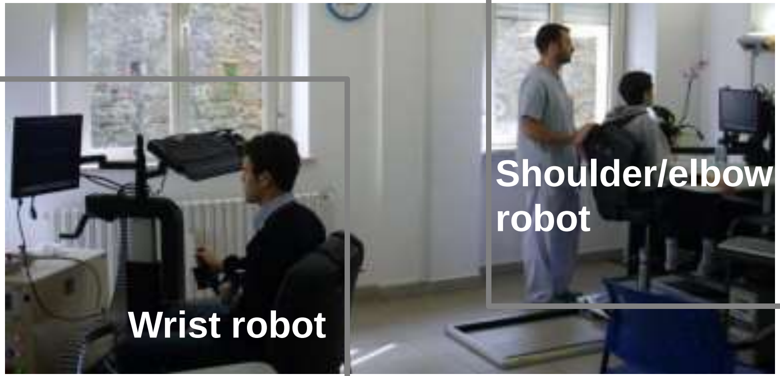

- n=450+ chronic and subacute **post-stroke** patients treated using robotic systems for upper limb rehabilitation *(50+ at Versilia Hospital, 400+ at Auxilium Vitae Volterra)*: **2nd largest sample size worldwide**
- Design and development of innovative robotic systems for upper limb rehabilitation
- Analysis of patient-ventilator interaction: development of software routine for automatic identification of respiratory asynchronies and assessment of patient effort (diaphragmatic EMG)
- Pulmonary telerehabilitation: low-cost and portable interactive videogames for home-based training
- Ventilatory response to exercise of n=90 elite soccer players

• S. Mazzoleni , P. Sale, M. Franceschini, S. Bigazzi, M.C. Carrozza, P. Dario, F. Posteraro. Effects of proximal and distal robot-assisted upper limb rehabilitation on chronic stroke recovery. *NeuroRehabilitation* 2013;33(1):33-9

• S. Mazzoleni, G. Montagnani, G. Vagheggini, L. Buono, F. Moretti, P. Dario, N. Ambrosino. Interactive videogame as rehabilitation tool of patients with chronic respiratory diseases: preliminary results of a feasibility study. *Respiratory Medicine* 2014; 108(10):1516–1524

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Robotic devices for robot-assisted upper limb rehabilitation

Proximal segments

MIME

InMotion 2.0

REHAROB

MIT-MANUS

NeReBot

ReoGo

Distal segments

Bi-Manu-Track

Reha-Digit

Reha-Slide

AMADEO

GLOREHA

InMotion WRIST

Supinator Extender

RiceWrist-S

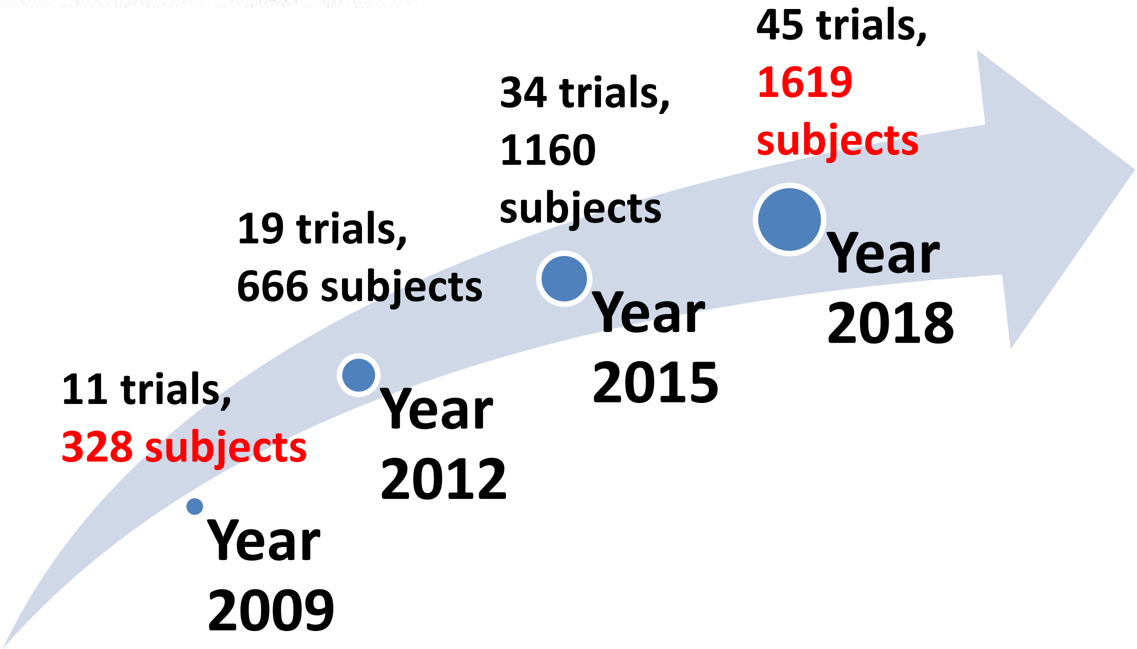
Cochrane Library
Cochrane Database of Systematic Reviews

Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke (Review)

Mehrholz J, Pohl M, Platz T, Kugler J, Elsner B

Aims:
To assess the effects of electromechanical and robot-assisted arm training for improving arm function in people who have had a stroke.

Selection Criteria:
RCTs comparing electromechanical and robot-assisted arm training for recovery of arm function with other rehabilitation or placebo interventions, or no treatment, for people after stroke.



The MIT-MANUS

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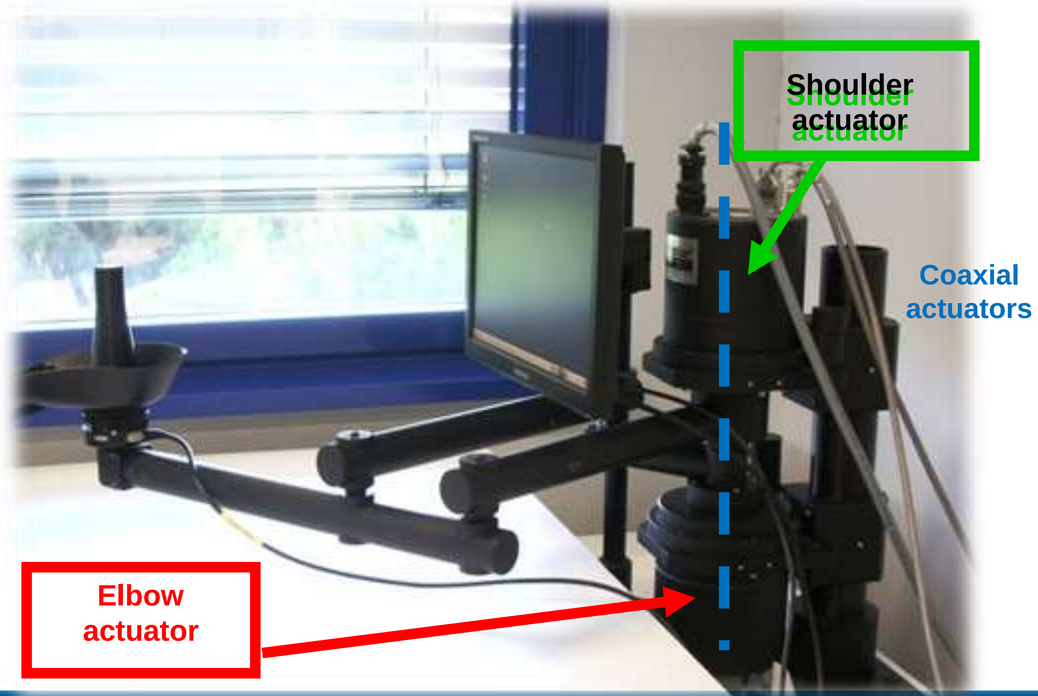
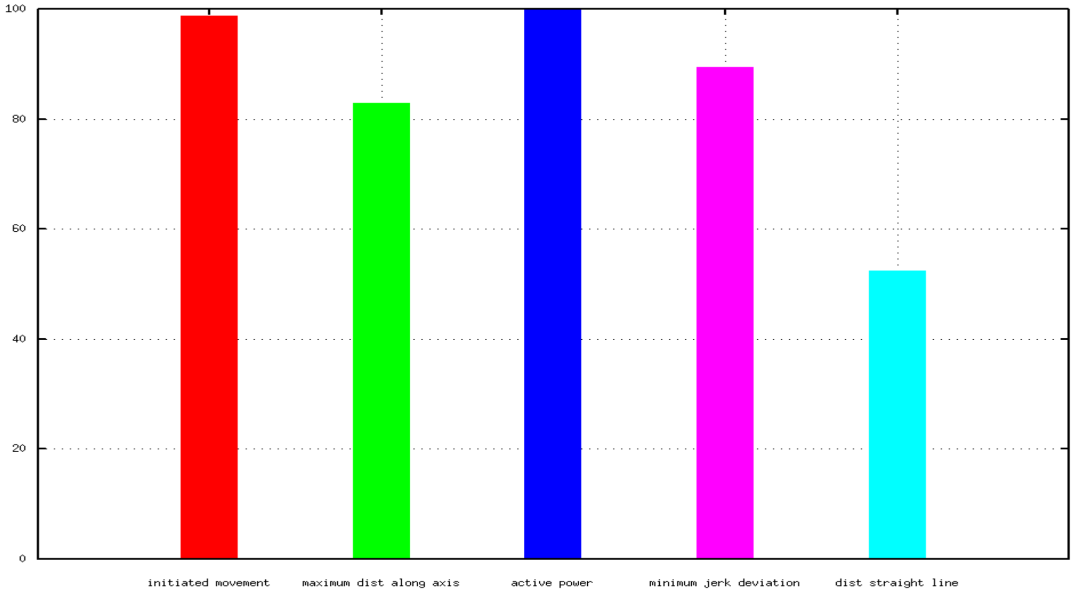


F. Posteraro, S. Mazzoleni, S. Aliboni, *et al*. Robot-mediated therapy for paretic upper limb of chronic ptients following neurological injury. *J Rehabil Med*, 41: 976-980, 2009.

Patient's visual feedback

- A visual performance display appears following **five series of repetitions**. Based on the patient performance, the program either increases or decreases the assistance provided to reach the targets.
- Display provides positive reinforcement to patient and encourages them to improve



PM1: Initiated Movement

PM2: Maximum Distance Along Target Axis

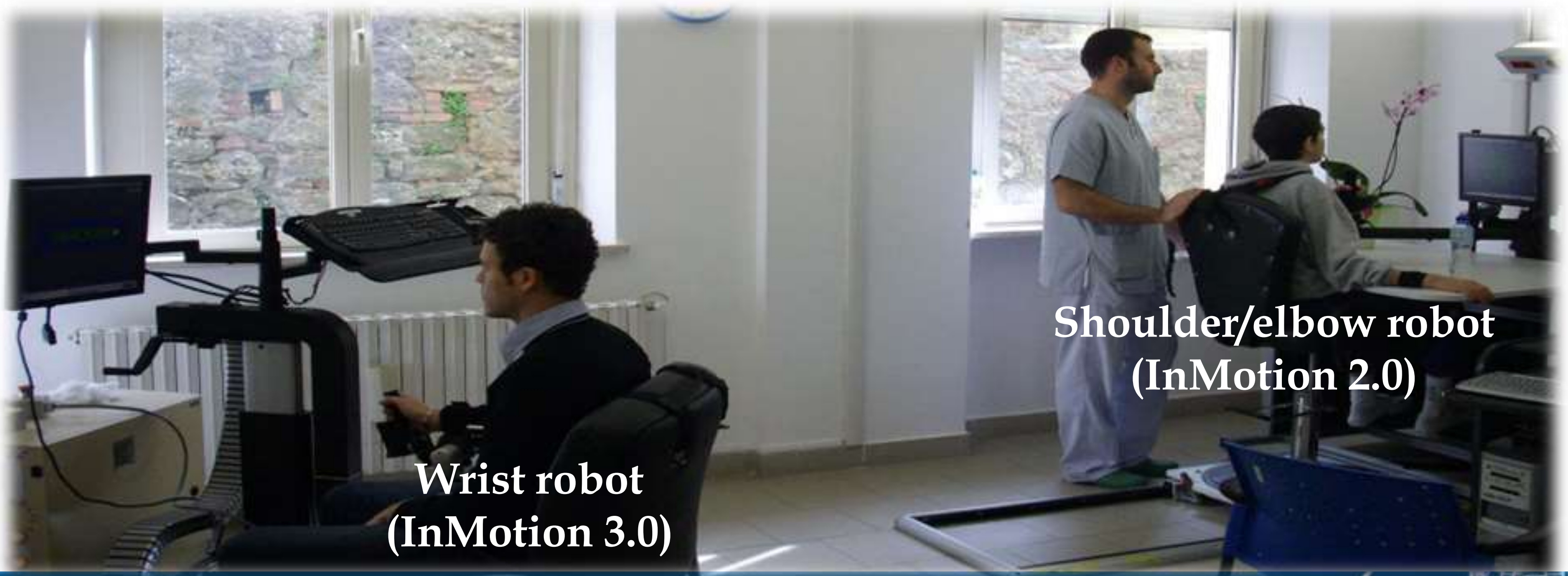
PM3: Active Power

PM4: Minimum jerk deviation (smoothness)

PM5: Distance from straight line (accuracy)

Rehabilitation Centre “Auxilium Vitae”, Volterra, Italy

Robotic systems for upper limb motor therapy



Robotic systems for upper limb motor therapy in stroke patiens: Our experience with MIT-MANUS

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Aim:

to **present the effectiveness of robot mediated therapy on the paretic upper limb** of an experimental group of 20 **chronic stroke** patients

Participants :

A group of **20 subjects**, age range 33–69 (mean age 53.3, standard deviation (SD) 11.2).

Methods:

Robot-mediated therapy was delivered using the MIT-MANUS, a robot designed for clinical neurological application

Subject ID	Age, years	DH	Pathology	AS	CM	MSS-SE Admission	MSS-SE Discharge	MSS-SE Follow-up
M01	61	R	Haemorrhagic stroke	R	3	9.6	14.2	13.4
M02	45	R	Haemorrhagic stroke	R	3	10.4	12.0	12.0
M03	62	R	Ischemic stroke	L	3	12.2	13.6	13.6
M04	53	R	Haemorrhagic stroke	R	3	14.4	17.8	17.8
F01	63	R	Haemorrhagic stroke	L	4	15.4	16.2	16.0
M05	64	R	Haemorrhagic stroke	R	3	10.6	12.2	11.4
M06	57	R	Haemorrhagic stroke	L	3	8.8	11.4	11.4
F02	47	R	Ischaemic stroke	L	1	1.6	1.6	1.6
M07	57	R	Ischaemic stroke	R	4	10.4	11.6	11.6
M08	62	R	Ischaemic stroke	L	3	12.8	16.2	14.4
M09	69	R	Ischaemic stroke	L	1	13.6	13.6	13.6
F03	36	R	Brain injury	L	3	14.6	15.0	18.8
M10	50	R	Brain injury	L	4	28.2	31.0	30.8
F04	63	R	Ischaemic stroke	L	3	13.8	16.2	18.2
M11	34	R	Ischaemic stroke	R	3	9.2	11.2	11.0
M12	41	R	Ischaemic stroke	L	3	17.6	20.2	18.0
F05	68	R	Ischaemic stroke	L	1	7.2	10.4	7.2
M13	52	R	Ischaemic stroke	R	3	13.2	13.6	13.4
F06	50	R	Brain injury	L	3	10.2	11.8	11.8
M14	33	R	Ischaemic stroke	L	5	35.2	37.4	37.4

AS: affected side; CM: Chedoke–McMaster Stroke Assessment; DH: dominant hand; L: left; MSS-SE: Motor Status Score – Shoulder-Elbow; R: right.

- **Adaptive**: system recognize subject's active movements even partially performed. It helps subject to terminate the initiated movement
- **Planar movements**
- Kinematical parameters at the end-effector

F. Posteraro, S. Mazzoleni, S. Aliboni, *et al*. Robot-mediated therapy for paretic upper limb of chronic ptients following neurological injury. *J Rehabil Med*, 41: 976-980, 2009.

Robotic systems for upper limb rehabilitation in sroke patients: our experience with MIT-MANUS

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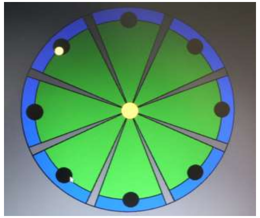

Table II. *Outcome measures comparison at admission and discharge*

	Admission		Discharge		
Evaluation	Median	IQR	Median	IQR	*p*
MSS-SE	12,800	10,350–14,800	14,200	11,950–16,600	<0.001
MAS shoulder	8,000	4,750–11,250	4,000	2,750–6,625	<0.001
MAS elbow	1,500	750–2,000	1,000	0–1,500	ns
ROM shoulder	440,000	408,750–566,250	550,000	477,500–647,500	<0.001
ROM elbow	440,000	417,500–460,000	460,000	450,000–460,000	<0.005

IQR: interquartile range; MAS: Modified Ashworth scale; MSS-SE: Motor Status Score – Shoulder-Elbow; ns: not significant; ROM: range of motion

F. Posteraro, S. Mazzoleni, S. Aliboni, *et al*. Robot-mediated therapy for paretic upper limb of chronic ptients following neurological injury. *J Rehabil Med*, 41: 976-980, 2009.

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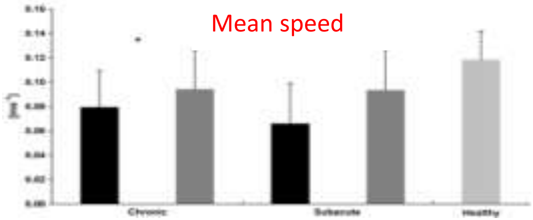
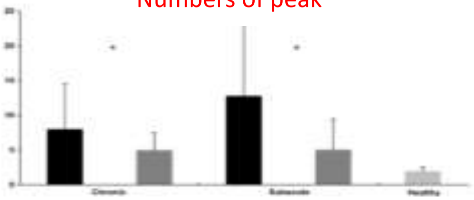
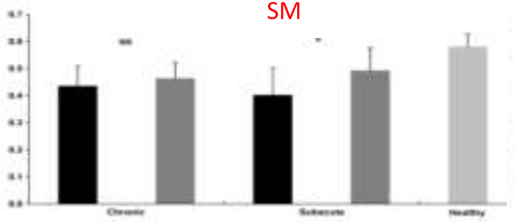
Mean speed



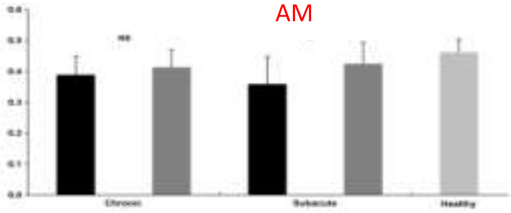
Numbers of peak



SM



AM



FMA/ue

	Pretreatment	Posttreatment	Change	P
Chronic	36.52 ± 22.83	44.20 ± 22.44	7.68 ± 6.23	NS
Subacute	40.42 ± 26.35	56.37 ± 26.25	15.95 ± 12.49	<0.05

MI

	Pretreatment	Posttreatment	Change	P
Chronic	20.92 ± 11.55	28.12 ± 13.11	7.20 ± 5.60	<0.05
Subacute	26.28 ± 12.10	35.66 ± 12.34	9.50 ± 7.83	<0.05

F. Posteraro, S. Mazzoleni, S. Aliboni, *et al*. Robot-mediated therapy for paretic upper limb of chronic ptients following neurological injury. *J Rehabil Med*, 41: 976-980, 2009.

Upper Limb Robot-Assisted Therapy in Chronic and Subacute Stroke Patients

A Kinematic Analysis

Stefano Mazzoleni, PhD
Patrizio Sale, MD
Micol Tiboni, PT
Marco Franceschini, MD
Maria Chiara Carrozza, PhD
Federico Posteraro, MD

American Journal of Physical Medicine & Rehabilitation

Aim:

to compare motor recovery in subacute and chronic stroke patients through clinical assessment scales and a set of kinematic parameters recorded using a robotic system

Subjects:

N=25 subacute stroke patients (25±7 days from acute event)

- Mean age: 70.2 ± 9.4 (range: 44-82 years)
- 16 M, 9 F

N=25 chronic stroke patients (>1 year from acute event)

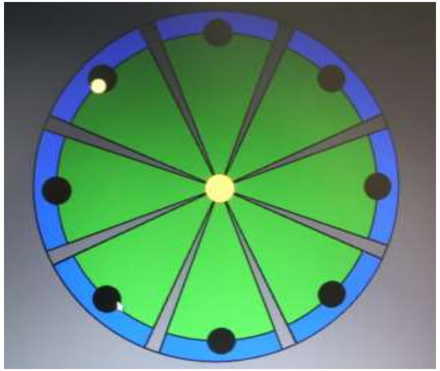
- mean age: 58.8 ±13.1 (range: 31-86 years)
- 17 M, 8 F

N=20 healthy subjects

- mean age: 38.0 ± 9.8 (range: 27-60 years)
- 9 M, 11 F

S. Mazzoleni, P. Sale, M. Tiboni, *et al*. Upper limb robot-assisted therapy in chronic and subacute stroke patients: a kinematic analysis. *American Journal of Physical and Medicine Rehabilitation*, 2013.

Methods



Intervention:

5 sessions/week, 4 weeks

- Reaching exercises
- Each session:
    - 16 not assisted movements *(Training test)*
    - 16 not assisted movements *(Record)*
    - 3 series of 320 robot assisted movements *(Adaptive)*

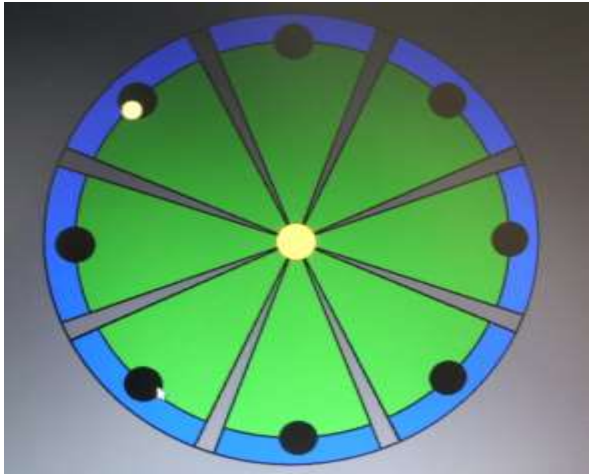
Clinical outcome measures:

- Fugl-Meyer Assessment (FMA) Scale – upper extremity section *(max 66)*
- Motricity index (MI) - upper limb component *(max 100)*

S. Mazzoleni, P. Sale, M. Tiboni, *et al*. Upper limb robot-assisted therapy in chronic and subacute stroke patients: a kinematic analysis. *American Journal of Physical and Medicine Rehabilitation*, 2013.

Kinematic parameters

- **Speed** $\overline{v_x} = \frac{1}{N}\sum_{k=1}^{N} v_x[k]$ $\overline{v_y} = \frac{1}{N}\sum_{k=1}^{N} v_y[k]$ $v_{xy} = \sqrt{(v_x[k])^2 + (v_y[k])^2}$ $\overline{v_{xy}} = \frac{1}{N}\sum_{k=1}^{N} v_{xy}[k]$
- **Smoothness**
  - Number of Speed Peaks (NSP)
  - Speed Metric $SM = \frac{\overline{v_{xy}}}{v_{peak}}$
  - Acceleration Metric $AM = \frac{\overline{a_{xy}}}{a_{peak}}$
- **Onset Movement Time**



S. Mazzoleni, P. Sale, M. Tiboni, *et al*. Upper limb robot-assisted therapy in chronic and subacute stroke patients: a kinematic analysis. *American Journal of Physical and Medicine Rehabilitation*, 2013.

Results: clinical outcome measures

FMA

	Pretreatment	Posttreatment	Change	*P*
Chronic	20.92 ± 11.55	28.12 ± 13.11	7.20 ± 5.60	<0.05
Subacute	26.28 ± 12.10	35.66 ± 12.34	9.50 ± 7.83	<0.05

Motricity Index

	Pretreatment	Posttreatment	Change	*P*
Chronic	36.52 ± 22.83	44.20 ± 22.44	7.68 ± 6.23	NS
Subacute	40.42 ± 26.35	56.37 ± 26.25	15.95 ± 12.49	<0.05

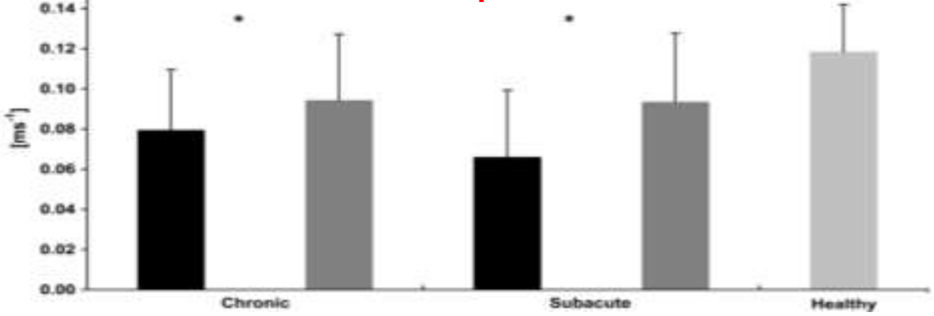
Kinematic parameters (subacute patients)

	20 Sessions	30 Sessions	*P*
v_{xy}, m/sec	0.10 ± 0.03	0.09 ± 0.03	NS
NSP	4.81 ± 4.10	4.52 ± 2.82	NS
SM	0.49 ± 0.07	0.50 ± 0.07	NS
AM	0.43 ± 0.06	0.45 ± 0.09	NS

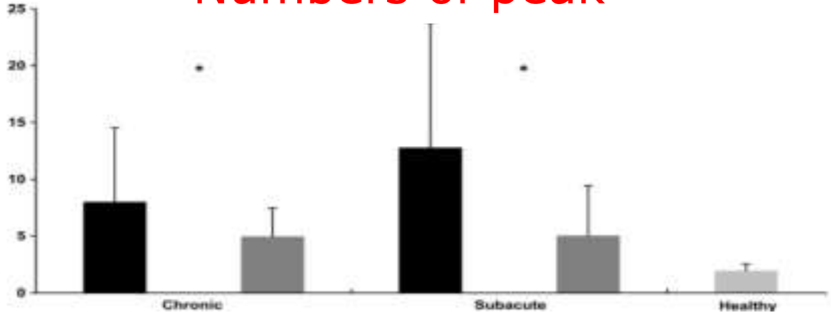
S. Mazzoleni, P. Sale, M. Tiboni, *et al*. Upper limb robot-assisted therapy in chronic and subacute stroke patients: a kinematic analysis. *American Journal of Physical and Medicine Rehabilitation,* 2013.

Results: kinematic parameters

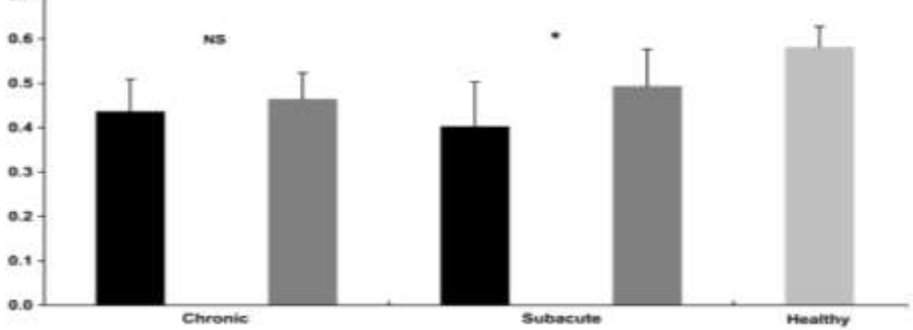
Mean speed



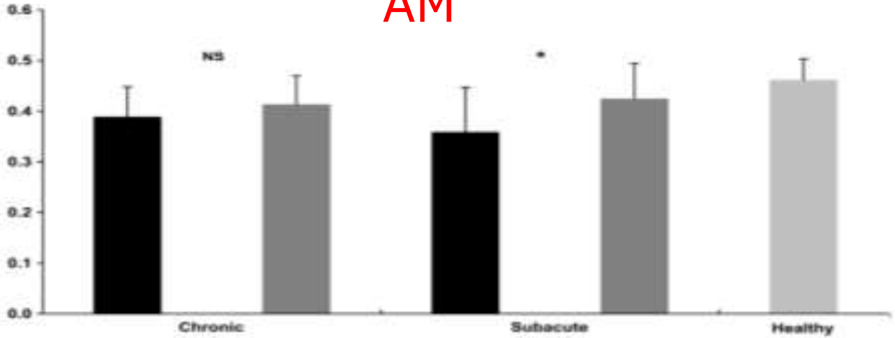
Numbers of peak



SM

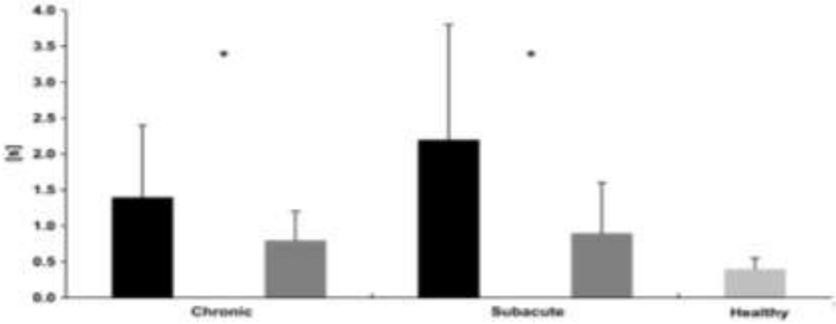


AM



S. Mazzoleni, P. Sale, M. Tiboni, *et al*. Upper limb robot-assisted therapy in chronic and subacute stroke patients: a kinematic analysis. *American Journal of Physical and Medicine Rehabilitation,* 2013.

Results: movement onset time and correlation among measures



Correlations

	Chronic		Subacute	
	FM[a]	MI[a]	FM[a]	MI[b]
AM	0.117[c]	−0.236[c]	−0.217[c]	−0.208[c]
NSP	−0.016[c]	0.310[c]	0.028[c]	0.043[c]
SM	0.123[c]	−0.337[c]	−0.208[c]	−0.130[c]
v_{xy}, mean	0.069[c]	−0.159[c]	−0.040[c]	−0.078[c]

[a]Pearson correlation coefficient.
[b]Spearman rank correlation coefficient.
[c]$P > 0.05$.

S. Mazzoleni, P. Sale, M. Tiboni, *et al*. Upper limb robot-assisted therapy in chronic and subacute stroke patients: a kinematic analysis. *American Journal of Physical and Medicine Rehabilitation*, 2013.

Robotic systems for upper limb rehabilitation in stroke patients

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di riferimento Regionale



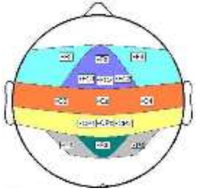
Stefano Mazzoleni
Vi Do Tran
Elena Battini

Biosemi Active Two system (16 channels)

Aim:

to present the results of an **innovative functional assessment** method for the upper limb in hemiparetic subjects, based on the **integrated analysis of biomechanical data** and **electroencephalographic signals** (EEG) recorded during reaching movements.

Robotic therapy can contribute to upper limb motor recovery: does it stimulate (and lead to activation of) cortex areas in the damaged hemisphere?

S. Mazzoleni, M. Coscia, G. Rossi, S. Aliboni, F. Posteraro, MC Carozza. Effects of an upper limb robot-mediated therapy on paretic upper limb in chronic hemiparetic subjects: a biomechanical and EEG-based approach for functional assessment. IEEE International Conference on Rehabilitation Robotics 2009.

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Methods:

- N=6 subjects took part in the experiment: N=4 healthy subjects (aged 24-48) and N=2 chronic hemiparetic subjects (aged 59-61): P01 left hemiparesis, P02 right hemiparesis
- In each session, subjects received 60 minutes of robot-mediated therapy, 5 sessions per week, 4 weeks

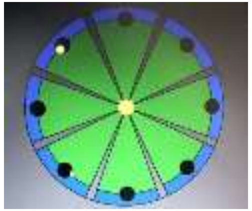
Biomechanical data recording

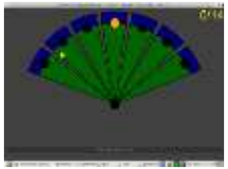
Week 1-2

Biomechanical data recording

Week 2-4

Biomechanical data recording





EEG recording

Week 1-2

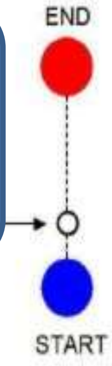
EEG recording

Week 2-4

EEG recording

10 Repetitions (Familiarization)

35 Repetitions (Recording)



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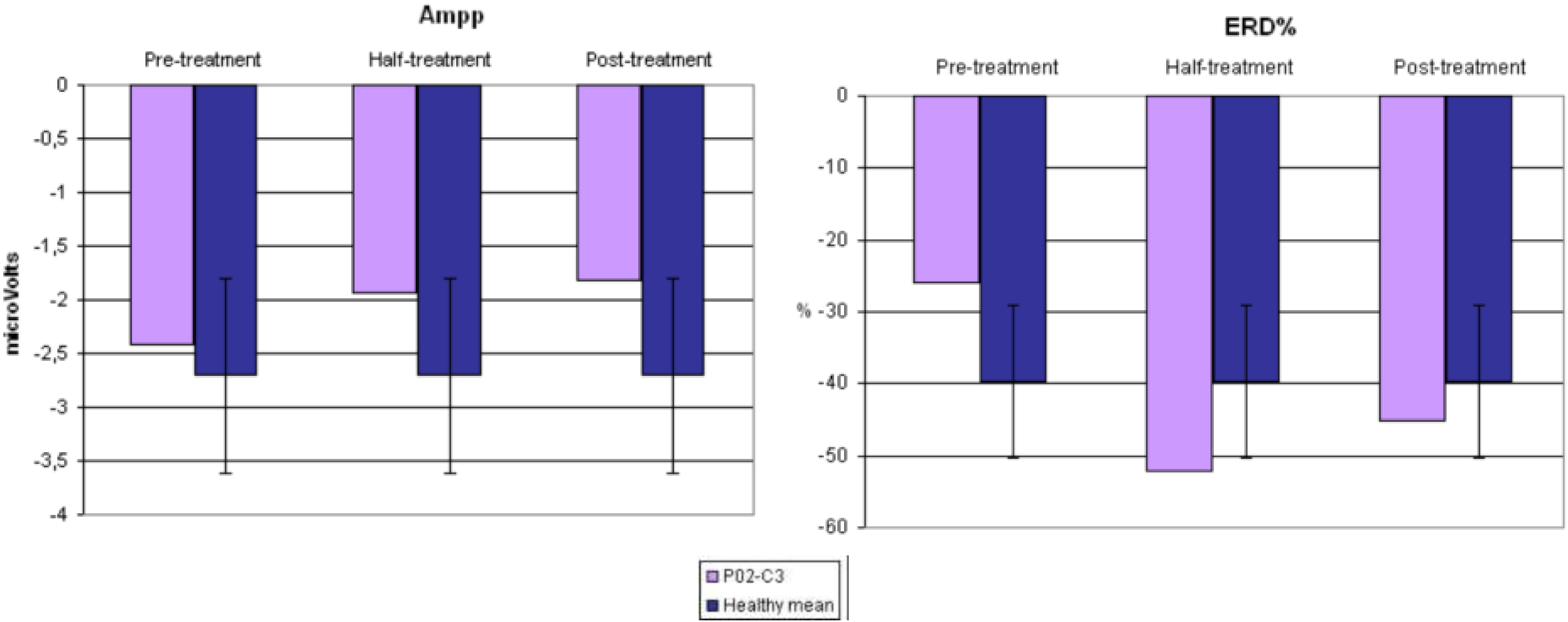

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Robotic systems for upper limb rehabilitation in stroke patients

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RIABILITAZIONE AUXILIUM VITÆ VOLTERRA
di riferimento Regionale


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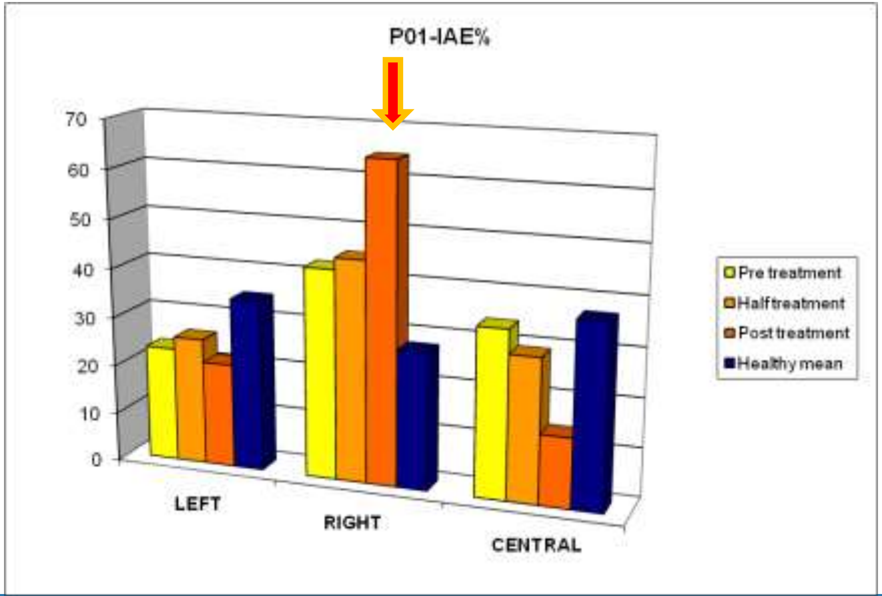
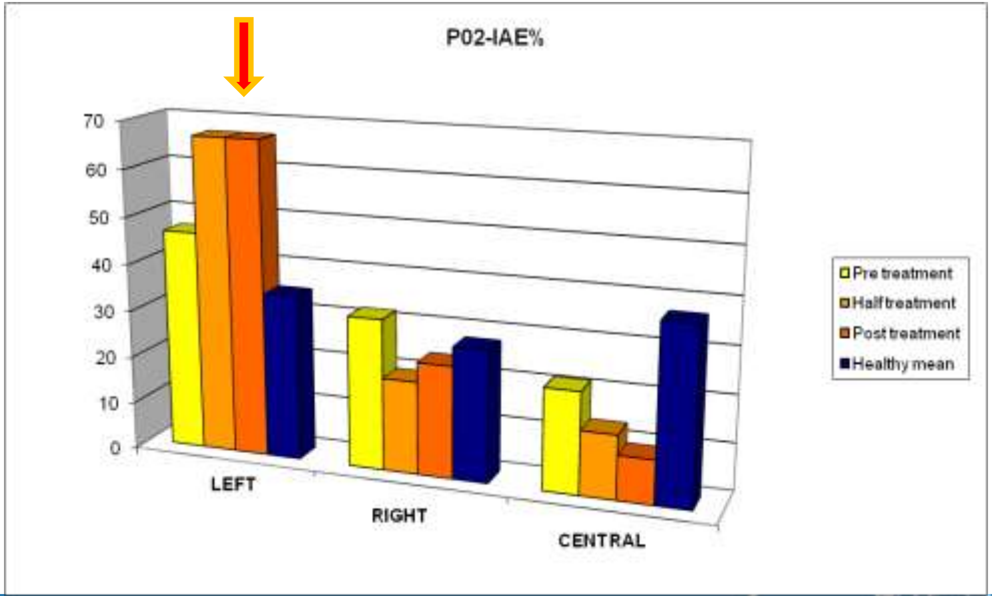
EEG analysis: results

Predominant activation of controlateral cortex hemisphere in healthy subjects, whereas during the robotic therapy treatment, a gradual activation of ipsilateral hemisphere was observed in both hemiparetic subjects





S. Mazzoleni, M. Coscia, G. Rossi, *et al*. Effects of an upper limb robot-mediated therapy on paretic upper limb in chronic hemiparetic subjects: a biomechanical and EEG-based approach for functional assessment. IEEE International Conference on Rehabilitation Robotics 2009.

Robotic systems for upper limb rehabilitation in stroke patients: our experience with InMotion 2.0

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Aim:

is to propose a **new methodology** in order to **evaluate the difference of recovery mechanisms** in stroke subjects in **subacute and chronic phase** by using the trend, before and after the upper limb robot-aided training, of **two biomechanical parameters, namely velocity and force.**

Participants:

- **N=8 subacute** stroke subjects, age range 18–82 (mean age 63.0 ± 21.3) years. Time from the acute event: 25 ± 7 days.
- **N=17 chronic** stroke subjects, age range 33-66 (mean age: 51.9 ± 0.7) years. Time from the acute event: at least 1 year.

Interventions:

- Each subject was asked to perform goal-directed, planar reaching tasks, moving from the centre target to each of 8 peripheral targets.
- Five robot-aided sessions per week for 6 weeks.

Subacute stroke subjects characteristics

ID	Age	DH	AS	CM	FM Admission	FM Discharge
S01	44	R	R	2	20.0	29.0
S02	70	R	R	2	19.0	47.0
S03	77	R	R	4	40.0	47.0
S04	18	R	R	2	15.0	25.0
S05	82	R	L	2	21.0	41.0
S06	70	R	L	5	21.0	28.0
S07	72	R	L	4	36.0	49.0
S08	71	R	L	2	18.0	25.0

Clinical Outcome measures:
- Motor Status Scale shoulder and elbow (MSS-SE) – chronic patients
- Fugl-Meyer (FM)-subacute

Biomechanical Parameters:
- Mean Forces
- Mean speed

Chronic stroke subjects characteristics

ID	Age	DH	AS	CM	MSS-SE Admission	MSS-SE Discharge
S09	61	R	R	3	9.6	14.2
S10	45	R	R	3	10.4	12.0
S11	53	R	R	3	14.4	17.8
S12	64	R	R	3	10.6	12.2
S13	57	R	R	4	10.4	11.6
S14	34	R	R	3	9.2	11.2
S15	52	R	R	3	13.2	13.6
S16	62	R	L	3	12.8	16.2
S17	57	R	L	3	8.8	11.4
S18	62	R	L	3	12.2	13.6
S19	36	R	L	3	14.6	15.0
S20	33	R	L	5	35.2	37.4
S21	50	R	L	4	28.2	31.0
S22	41	R	L	3	17.6	20.2
S23	63	R	L	4	15.4	16.2
S24	50	R	L	3	10.2	11.8
S25	63	R	L	3	13.8	16.2

S. Mazzoleni, L. Puzzolante, L. Zollo, P.Dario and F. Posteraro. Mechanisms of motor recovery in chronic and subacute Stroke patients following a robot-aided training. IEEE TRANSACTIONS ON HAPTICS, 7(2), 2014.

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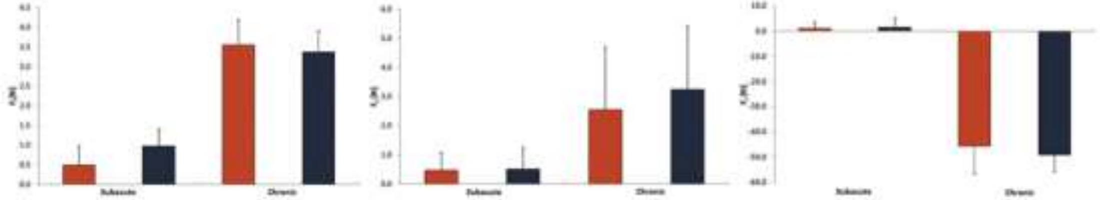
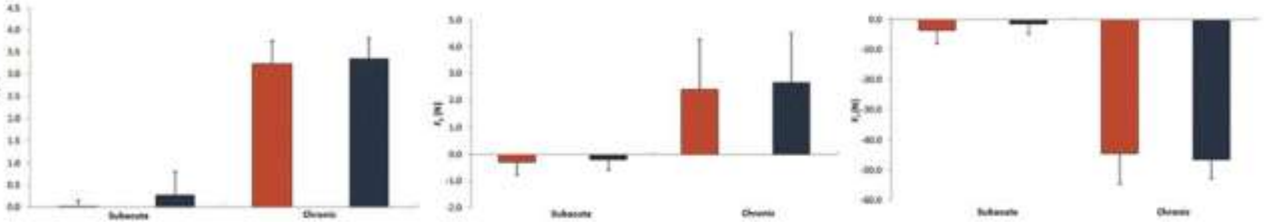
Clinical outcome measures

	FM (subacute)	MSS-SE (chronic)
PRE	23.75 ± 9.07	14.50 ± 7.02
POST	36.37 ± 10.62	16.56 ± 7.18
Change	12.62 ± 7.61	2.06 ± 1.12
p	< 0.05	< 0.001

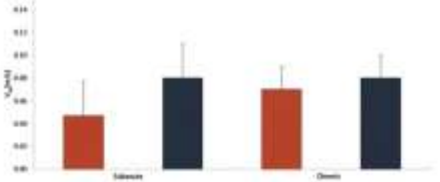
Mean Force before and after the robotic-aided training in direction Nt



Mean Force before and after the robotic-aided training



Mean Speed



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Haptic device for upper limb rehabilitation in stroke patients: a pilot study

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Aim:

to evaluate the effects of upper limb robot-assisted rehabilitation on motor recovery in stroke patients who underwent a treatment based on **a haptic device.**

Methods:

- **N=23 subacute stroke patients** (time from acute event: 14-35 days), mean age: 67.3 ± 11.7, 10 M, 13 F
- **N=16 chronic stroke patients** (time from acute event: 12-84 months), mean age: 66.9 ± 9.6, 10 M, 6 F
- **N=13 healthy subjects**, mean age: 43.9 ± 8.4, 8 M, 15 F

ID	Age	Gender	Type of lesion	Time since acute event (day)	Number of sessions	Chedoke-McMaster Stroke Assessment
1	74	F	I	17.00	26	4
2	74	M	E	24.00	24	5
3	72	F	I	35.00	19	5
4	72	M	E	17.00	25	5
5	69	F	H	33.00	25	6
6	69	F	H	34.00	23	6
7	84	F	I	28.00	19	2
8	45	M	I	35.00	21	5
9	69	F	I	22.00	36	5
10	76	F	I	18.00	24	6
11	75	M	I	24.00	30	5
12	61	F	I	14.00	27	4
13	59	M	I	24.00	29	4
14	63	M	I	26.00	24	4
15	53	F	I	60.00	23	5
16	79	M	I	14.00	21	6
17	46	M	H	17.00	25	5
18	50	F	I	29.00	28	2
19	64	F	I	30.00	22	6
20	81	F	I	20.00	28	4
21	79	F	I	30.00	29	5
22	53	M	I	35.00	23	6
23	81	M	I	26.00	26	6

ID	Age	Gender	Type of lesion	Time since acute event (months)	Number of sessions	Chedoke-McMaster Stroke Assessment
1	66	M	I	73.27	19	4
2	60	F	I	15.97	19	2
3	72	M	I	15.03	24	2
4	75	F	H	43.27	23	5
5	69	M	I	42.00	21	3
6	74	M	I	57.00	23	3
7	67	M	I	84.93	20	5
8	73	F	H	178.63	19	2
9	58	M	I	16.77	20	4
10	75	F	H	50.00	20	5
11	68	F	I	87.60	19	4
12	64	M	I	13.63	32	4
13	54	M	I	12.03	21	6
14	78	M	I	18.07	21	3
15	42	M	I	18.97	27	1
16	76	F	H	57.47	19	2

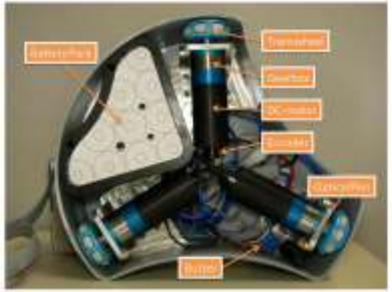
S. Mazzoleni, E. Battini, R. Crecchi, P. Dario, F. Posteraro. "Upper limb robot-assisted therapy in subacute and chronic stroke patients using an innovative end-effector haptic device: a pilot study." NeuroRehabilitation 2018 (42), 43-52.

Haptic device for upper limb rehabilitation in stroke patients: a pilot study

Stefano Mazzoleni **Elena Battini**

Methods:

- The CE-marked MOTORE (Mobile robot for upper limb neurOrtho Rehabilitation, Humanware Srl, Pisa, Italy)/Armotion system was used in this study.



- **10 batteries** (11.1 V)
- A **3-axes load cell** embedded in the handle is used to record patient-robot interaction forces
- **3 omnidirectional wheels** (Konylak Coorporation Tranwheels) which are actuated by **three DC motors** positioned at 120 degrees and based on **the Killough's kinematical model**
- an **absolute localization** system based on odometry from motor encoders and an optical sensor based on **Anoto® technology**
- **Bluetooth connection**
- **Active**, **assist-as-needed** and **passive control modalities**

Different exercises characterized by (i) visual and haptic cues, (ii) graphical scenario and (iii) performance parameters.

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Clinical Assessment

- Modified Ashworth Scale (MAS)
- Fugl-Meyer Scale upper extremity section (FM/ue)
- Motricity Index (MI)
- Box and Block Test (B&B)
- Medical Research Council Scale (MRC)
- Modified Barthel Index (mBI)

Statistical analysis

The **Wilcoxon signed rank test** was used to compare differences between clinical outcome measures and kinematic parameters.
Significance was set at $p < 0.05$

Kinematic parameters

- *mean speed* $v_{xy} = \frac{\sum_{i=1}^{5} \sqrt[2]{{v_{xi}}^2 + {v_{yi}}^2}}{5}$
- *maximum speed;*
- *mean time;*
- *path length* (total length: 768 mm);
- mean error, defined as the minimum distance between the
- ideal and the actual patient trajectory;
- *jerk parameters* $J = \sqrt[2]{0.5 * \int_{t_{start}}^{t_{end}} jerk^2(t)dt * \frac{duration^5}{length^2}}$
- *mean force* $F_{xy} = \frac{\sum_{i=1}^{5} \sqrt[2]{{F_{xi}}^2 + {F_{yi}}^2}}{5}$
- *mean energy expenditure*, representing the mean work carried out by the patient to executing the first five laps;
- *active patient-robot interaction percentage*, representing the percentage of elapsed time under the active modality.

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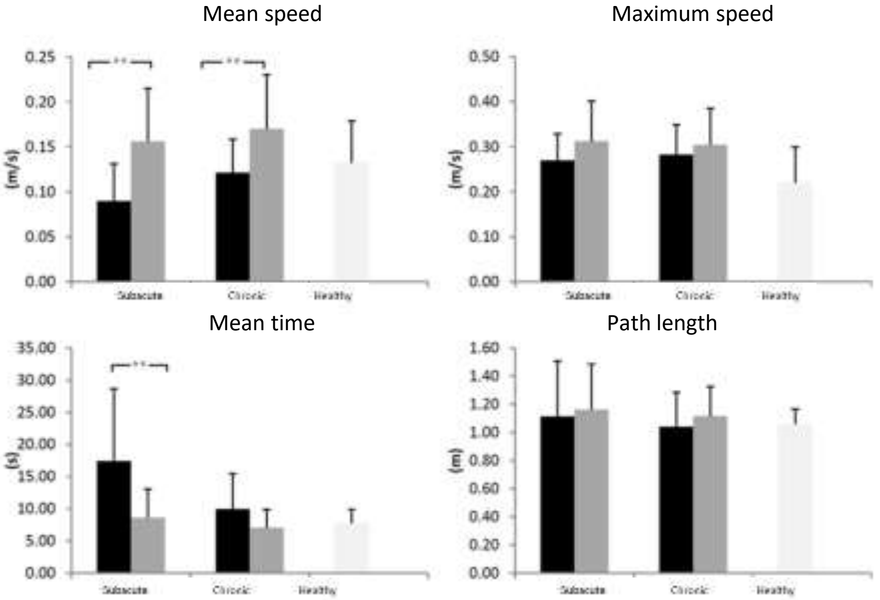
	T0	T1	Change
FM/ue			
Subacute	37.57 ± 17.96	52.00 ± 13.39**	13.82 ± 11.84
Chronic	26.63 ± 16.55	33.87 ± 19.66**	7.25 ± 4.25
MAS-shoulder			
Subacute	0.21 ± 0.32	0.13 ± 0.45	−0.09 ± 0.42
Chronic	1.44 ± 1.09	1.06 ± 0.85	−0.38 ± 0.62
MAS-elbow			
Subacute	0.69 ± 0.97	0.30 ± 0.55	−0.44 ± 0.89
Chronic	2.19 ± 1.05	1.50 ± 0.73*	−0.69 ± 0.70
MAS-wrist			
Subacute	0.26 ± 0.54	0.08 ± 0.29	−0.20 ± 0.49
Chronic	1.88 ± 1.45	1.13 ± 1.02*	−0.75 ± 1.06
MI			
Subacute	60.04 ± 15.67	77.88 ± 14.66**	17.73 ± 11.35
Chronic	51.13 ± 21.25	58.94 ± 22.16*	7.81 ± 9.38
MRC-shoulder			
Subacute	60.04 ± 15.67	77.87 ± 14.66	4.18 ± 3.84
Chronic	13.50 ± 6.78	15.31 ± 7.12	1.81 ± 1.94
MRC-elbow			
Subacute	16.61 ± 6.13	20.91 ± 5.73	1.31 ± 1.32
Chronic	5.25 ± 2.82	6.25 ± 2.70	1.00 ± 0.82
MRC-wrist			
Subacute	6.52 ± 1.90	7.83 ± 1.67	1.40 ± 1.71
Chronic	3.56 ± 2.80	4.38 ± 2.92	0.81 ± 1.42
B&B			
Subacute	10.00 ± 9.26	23.13 ± 12.41**	12.59 ± 10.69
Chronic	10.13 ± 10.59	14.75 ± 13.89**	4.63 ± 4.87
MBI			
Subacute	44.43 ± 22.49	77.91 ± 25.73**	33.50 ± 18.75
Chronic	85.63 ± 11.78	87.38 ± 10.79	1.75 ± 4.31



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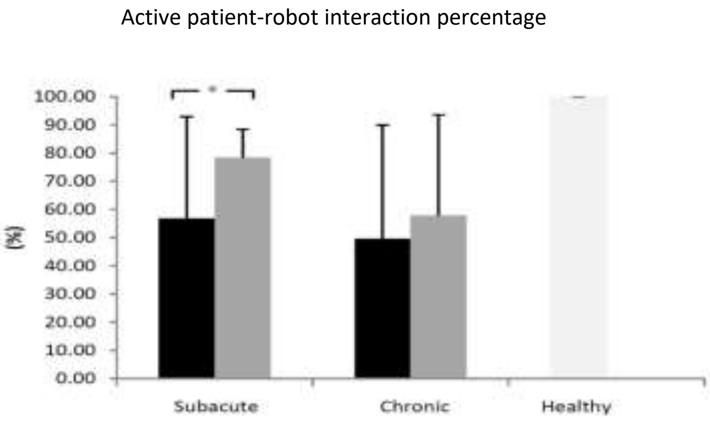

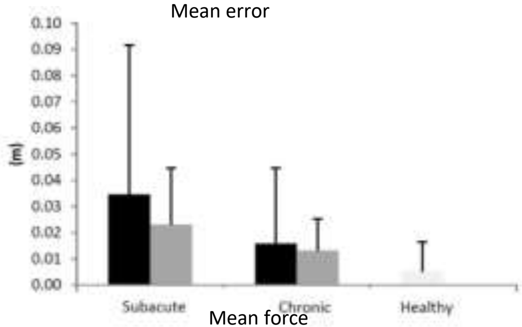

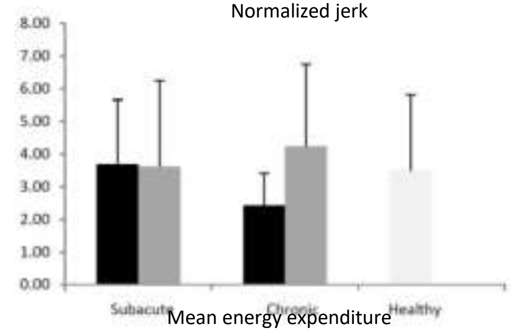

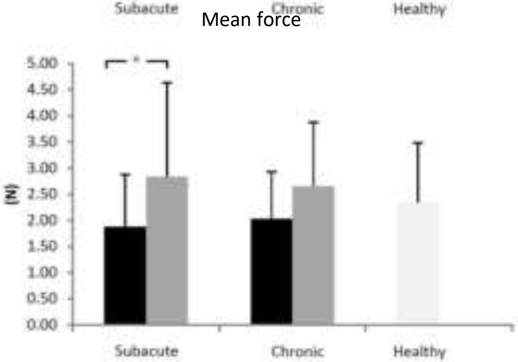

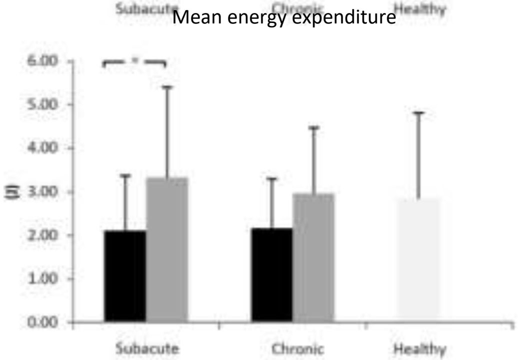

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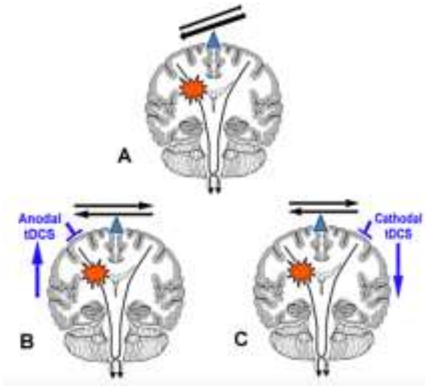
Interemispheric competition

Balanced cerebral emispheres through callosum connections by *interemispheric mutual inhibition*

Cerebrovascular accident



(Schlaug et al., *Arch Neurol*. 2008)

Reduced inhibitory activity in the affected hemisphere due to:

- Lesion
- Abnormal transcallosum inhibition

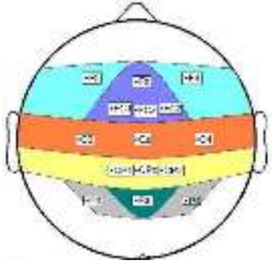
Large functional impact and correlation with motor recovery

Explanation of increased excitability of non-affected hemisphere:

- Adaptation to lesion
- Determinant factor in pathophysiology of impairment

New rehabilitation strategies ⟷ Balance recovery

Combined robot-assisted wrist rehabilitation and transcranial Direct Current Stimulation (tDCS) in subacute stroke



Study design: RCT "sham controlled"
Patients: n=40 (age 18-79 yrs) stroke survivors with upper limb impairment (alfa<0.05; power=0.80)
Treatment: 5 sessions/week, 6 weeks
Follow-up: 6 months

Study Group: wrist robot + tDCS *(anodal, 20 min, electrodes 35 cm^2, 2 mA, anodal electrode placed over the presumed hand area of lesioned hemisphere, and cathodal electrode above contralateral orbit)*

Control Group: wrist robot + tDCS *(sham)*

Inclusion criteria: (i) persons affected by first supratentorial stroke, whose onset time is 25±7 days; (ii) upper limb hemiparesis; (iii) cognitive and speech abilities sufficient to understand instructions and to provide informed consent; (iv) absence of intense pain due to passive wrist mobilization assessed by VAS < 3 (range 0-10); (v) ability to provide written informed consent

Exclusion criteria: (i) previous epilepsy seizures, (ii) severe EEG abnormalities, (iii) previous neurosurgery interventions including metallic elements, (iv) anticonvulsant medications, (v) inability to keep sitting posture and (vi) other current severe medical problems

Characteristics	Chronic group (CG) (n=20)	Subacute group (SG) (n=20)	p (two groups)
Age (range)	62.90± 8.88 (38-78)	66.40± 16.20 (24-88)	0.332[b]
Gender (F/M)	6/14	11/9	0.200[a]
Hemiparesis (R/L)	9/11	12/8	0.527[a]
Dominant side (R/L)	19/1	19/1	1.000[a]
Hemiparesis on domint side (Yes/No)	8/12	11/9	0.527[a]
Pathology (i/h)	14/6	17/3	0.451[a]
Chedoke-McMaster score (range)	3.90 ± 1.25 (2-6)	4.95± 1.05 (3-6)	0.017[b]
FM/w	4.75 ± 3.23	4.45 ± 3.27	0.860[b]
FM/se	22.10 ± 10.13	22.20 ± 8.85	0.985[b]
FM/ue	37.85 ± 19.33	35.40 ± 16.92	0.571[b]
MAS/w	1.30 ± 1.30	1.45 ± 2.33	0.893[b]
MI	59.25 ± 16.10	59.55 ± 13.07	1.000[b]
B&B	18.45 ± 13.38	13.20 ± 10.96	0.245[b]

S. Mazzoleni, V. D. Tran, P.Dario and F. Posteraro. Wrist robot-assisted rehabilitation treatment in subacute and chronic stroke patients: from distal-to-proximal motor recovery. IEEE Transaction on Neural Systems and Rehabilitation Engineering. 26(9), 1889-1896, 2018.

Wrist robot-assisted rehabilitation and tDCS in subacute stroke patients

Experimental Group (EG)

	Pre-Treatment	Post-Treatment	p
FM/w	3.65 ± 2.8	6.45 ± 3.39	<0.001[b]
FM/se	20.40 ± 10.51	26.9 ± 9.39	<0.001[a]
FM/ue	34.20 ± 18.35	46.20 ± 19.36	<0.001[b]
MAS/w	1.1 ± 1.86	0.90 ± 1.52	0.313[b]
MI	55.75 ± 25.22	71.35 ± 18.75	<0.001[a]
B&B	15.95 ± 12.10	24.35 ± 16.37	0.002[a]

Control Group (CG)

	Pre-Treatment	Post-Treatment	p
FM/w	4.47 ± 3.01	6.74 ± 3.16	<0.001[b]
FM/se	21.37 ± 8.06	27.63 ± 6.60	<0.001[a]
FM/ue	34.11 ± 15.48	49.84 ± 15.38	<0.001[a]
MAS/w	1.58 ± 2.34	1.21 ± 2.42	0.031[b]
MI	59.68 ± 12.15	73.79 ±14.16	<0.001[b]
B&B	12.32 ±10.41	20.63 ± 10.26	<0.001[a]

[a]: t-test, [b]: Mann-Whitney rank sum test

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[a]: t-test, [b]: Mann-Whitney rank sum test

	Baseline			Change after treatment		
	CG (mean ± SD)	EG (mean ± SD)	p	CG (mean ± SD)	EG (mean ± SD)	p
FM/w	4.47 ± 3.01	3.65 ± 2.8	0.381[a]	2.26 ± 2.42	2.8 ± 2.12	0.311[b]
FM/se	21.37 ± 8.06	20.40 ± 10.51	0.749[a]	6.26 ± 6.51	6.50 ± 5.18	0.900[a]
FM/ue	34.11 ± 15.48	34.20 ± 18.35	0.986[a]	15.74 ± 13.75	12.00 ± 8.5	0.536[b]
MAS/w	1.58 ± 2.34	1.1 ± 1.86	0.471[b]	-0.37 ± 0.60	-0.20 ± 0.77	0.532[b]
MI	59.68 ± 12.15	55.75 ± 25.22	0.843[b]	14.11 ± 10.66	15.60 ± 9.74	0.650[a]
B&B	12.32 ±10.41	15.95 ± 12.10	0.322[a]	8.32 ± 8.56	8.40 ± 10.24	0.978[a]

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Wrist robot-assisted rehabilitation and tDCS in subacute stroke patients

	FM/w	FM/se	FM/ue	MAS/w	MI	B&B
FM/w	1	0.0321	**0.673***	-0.268	0.282	0.252
FM/se	**0.799***	1	**0.665***	0.009	-0.023	-0.037
FM/ue	**0.680***	**0.784***	1	-0.308	0.404	0.257
MAS/w	-0.011	0.008	-0.007	1	-0.391	0.053
MI	**0.707***	**0.713***	**0.622***	0.114	1	**0.552***
B&B	0.401	**0.513***	0.386	0.133	**0.662***	1

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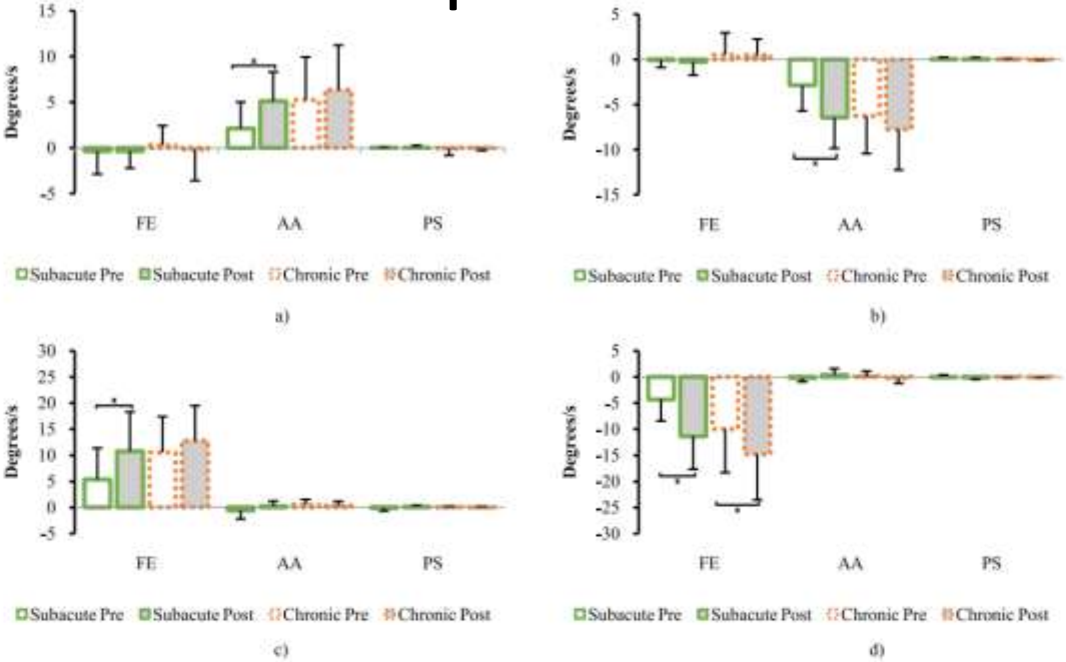
Wrist robot-assisted rehabilitation and tDCS in subacute stroke patients



Mean velocity

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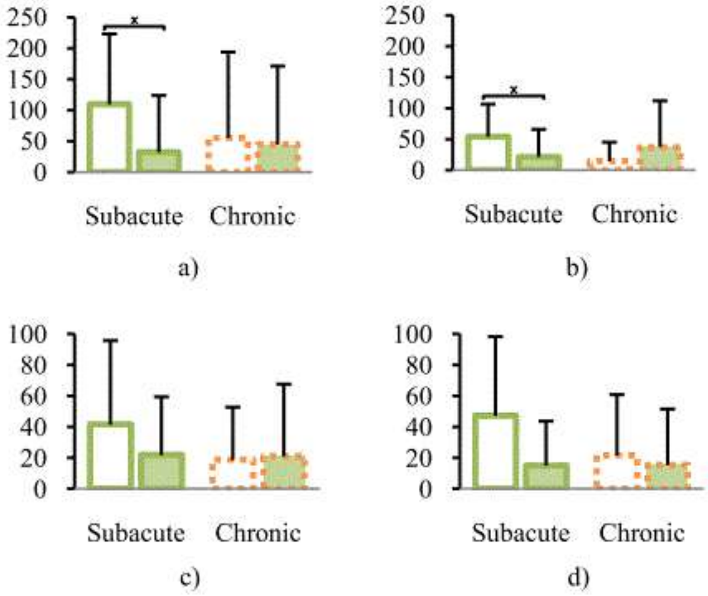
Wrist robot-assisted rehabilitation and tDCS in subacute stroke patients

Normalized jerk



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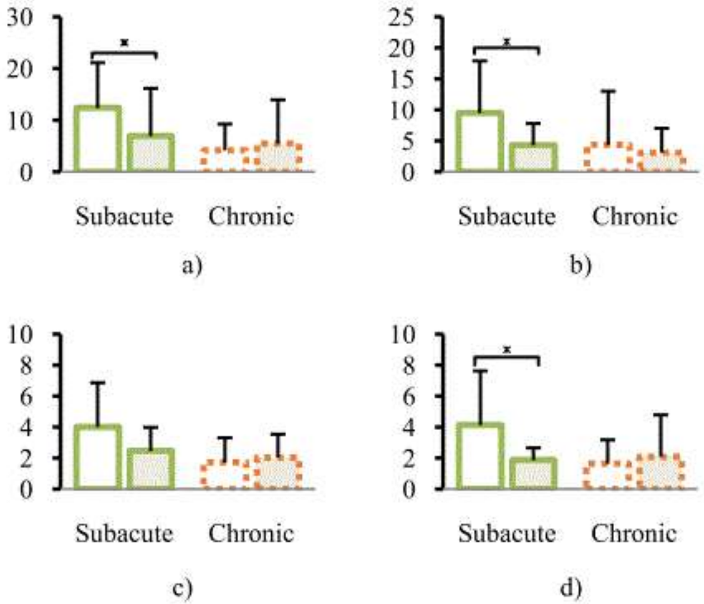

S. Mazzoleni, V. D. Tran, P.Dario and F. Posteraro. Wrist robot-assisted rehabilitation treatment in subacute and chronic stroke patients: from distal-to-proximal motor recovery. IEEE Transaction on Neural Systems and Rehabilitation Engineering. 26(9), 1889-1896, 2018.

Robot-assisted rehabilitation: novelty of results

- **Innovative assessment methods** based on (i) **interaction forces** *(Mazzoleni et al., IEEE Trans Haptics 2013)* and angular deviations from mean effort at the robot's end-effector in chronic post-stroke patients *(Mazzoleni et al., Applied Bionics and Biomechanics, 2011)* and (ii) **kinematic parameters** in subacute post-stroke patients *(Mazzoleni et al., Am J Phys Med Rehab 2013)*

- Proof of **effectiveness of robot-assisted treatment** in chronic stroke patients *(Posteraro et al., J Rehab Med 2009)* using **proximal/distal approach** *(Mazzoleni et al., Neurorehab 2013)*

Motion tracking for quantitative and qualitative Assessment of Upper Limb Movements Following Acromioclavicular Joint Ligament Reconstruction: A pilot Study

Centro Clinico di Riabilitazione Multispecialistico RIABILITAZIONE AUXILIUM VITAE VOLTERRA di riferimento Regionale


Stefano Mazzoleni


Elena Battini

Aim:

- to propose a **quantitative** and **qualitative assessment** of upper limb motor performance by means of a **mechatronic device** in patients who underwent a **surgical procedure for ligament reconstruction following ACJ dislocation**

Methods:

- Five patients (men, mean age: 40 ± 12 years, range: 20-51 years) with acute Rockwood type III and V ACJ dislocation

Patient ID	Age	Surgery date	FU time (months)	DS	IS	Injury cause	Classification (type)	CMS IS	CMS /IS
1	51	28/05/2012	36	R	L	accident	V	95	100
2	45	27/08/2010	55	R	R	sport	III	98	100
3	20	30/05/2012	34	L	R	sport	V	92	100
4	39	20/07/2011	44	R	R	accident	III	98	100
5	45	15/04/2011	48	R	L	sport	III	100	100

S. Mazzoleni, E. Battini, M.Galgani, M. Tinucci, P. Dario and G. Calvosa. Motion Tracking for Quantitative and Qualitative Assessment of Upper Limb Movements Following Acromioclavicular Joint Ligament Reconstruction: A pilot Study The Open Biomedical Engineering Journal. 12, 135-146, 2018.

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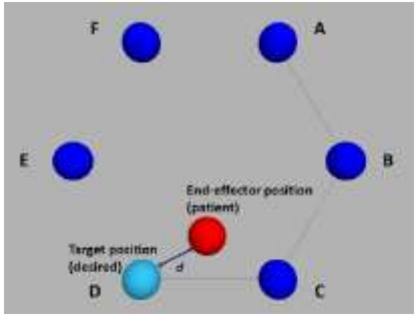
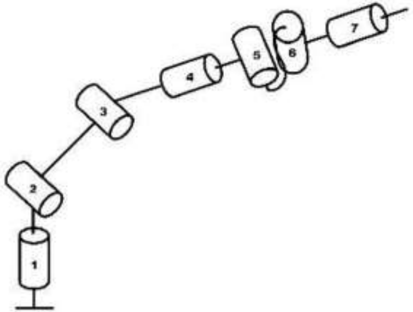
RIABILITAZIONE AUXILIUM VITÆ VOLTERRA
di riferimento Regionale

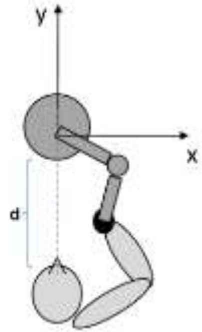

Stefano Mazzoleni


Elena Battini

The **ULTRA** (Upper Limb TRAcker, Humanware Srl, Pisa, Italy) system, a **passive end-effector mechatronic** device was used in this study. It is an articulated mechanical structure formed by 7 rotoidal joints corresponding to 7 Degrees Of Freedom (DOFs) divided as follows: 2 DOFs in correspondence of the shoulder joint, 1 DOF in correspondence of the elbow joint and 4 DOFs in correspondence of the wrist joint.







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Motion Tracking for Quantitative and Qualitative Assessment of Upper Limb Movements Following Acromioclavicular Joint Ligament Reconstruction: A pilot Study

Stefano Mazzoleni

Elena Battini

Assessment:

- Constant-Murley Score (CMS)
- Final Mean Time (FMT)
- Mean Distance (MD)
- Speed Metric (SM)
- Final Mean Movement Deviation (FMMD)
- Number of Peaks in Speeds Profile (NSP)
- Normalized Reaching Speed (NRS)
- Normalized jerk

$$MD = \frac{\sum_{k=1}^{N} |d_k|}{N} \quad (1)$$

$$SM = \frac{\overline{v}_{xy}}{v_{peak}}$$

$$NRS = \frac{v_{xy_{\max}} - \overline{v}_{xy}}{v_{xy_{\max}}} \quad (2)$$

CMS: scale based on a 100-point scoring system that provides a global score based on weighted measures of physical impairments ROM and strength

The CMS is divided into four domains: pain (15 points), activities of daily living (20 points),strength (25 points) and range of motion (40 points): the higher the score, the higher the quality of the function

S. Mazzoleni, E. Battini, M.Galgani, M. Tinucci, P. Dario and G. Calvosa. Motion Tracking for Quantitative and Qualitative Assessment of Upper Limb Movements Following Acromioclavicular Joint Ligament Reconstruction: A pilot Study The Open Biomedical Engineering Journal. 12, 135-146, 2018.

Motion Tracking for Quantitative and Qualitative Assessment of Upper Limb Movements Following Acromioclavicular Joint Ligament Reconstruction: A pilot Study

Centro Clinico di Riabilitazione Multispecialistico
RIABILITAZIONE AUXILIUM VITÆ VOLTERRA
di riferimento Regionale


Stefano Mazzoleni

Elena Battini

Results

	IPA	AB	BC	CD	DE	EF
FMMD	0.34	0.84	0.48	0.34	0.77	0.26
FMT	0.07	0.15	0.41	0.95	0.19	0.12
MD	NC	0.19	0.45	0.79	0.38	0.19
NSP	NC	0.53	0.19	0.22	0.25	0.63
SM	NC	0.91	0.80	0.58	0.17	0.79
NRS	NC	0.35	0.93	0.71	0.69	0.80
Normalized Jerk	NC	0.37	0.36	0.89	0.06	0.49

S. Mazzoleni, E. Battini, M.Galgani, M. Tinucci, P. Dario and G. Calvosa. Motion Tracking for Quantitative and Qualitative Assessment of Upper Limb Movements Following Acromioclavicular Joint Ligament Reconstruction: A pilot Study The Open Biomedical Engineering Journal. 12, 135-146, 2018.

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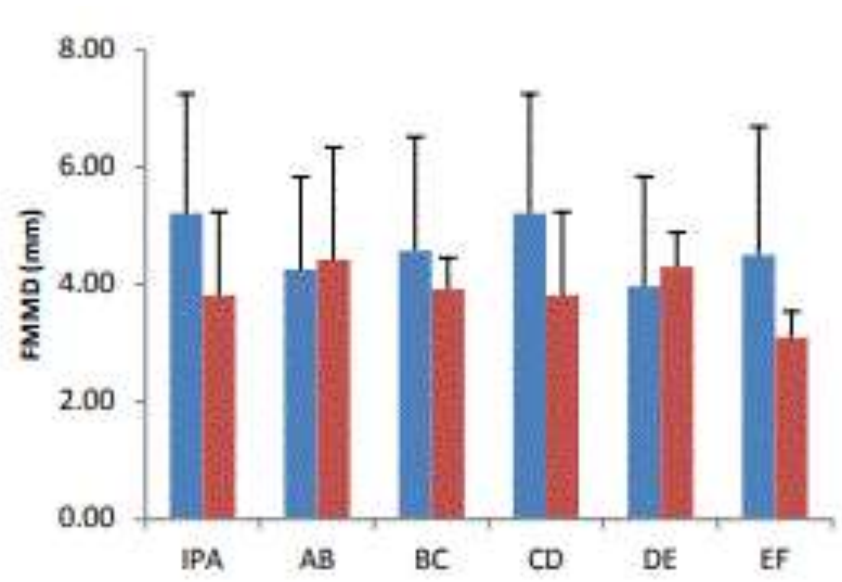

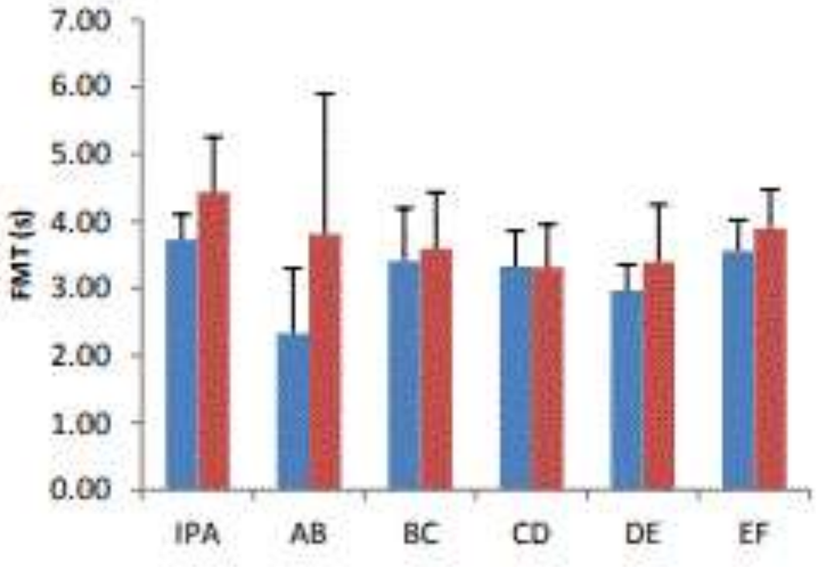

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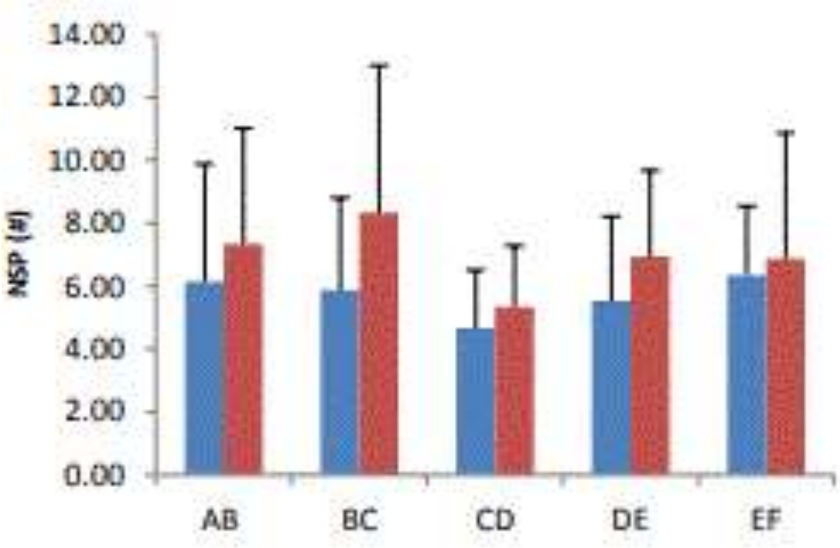

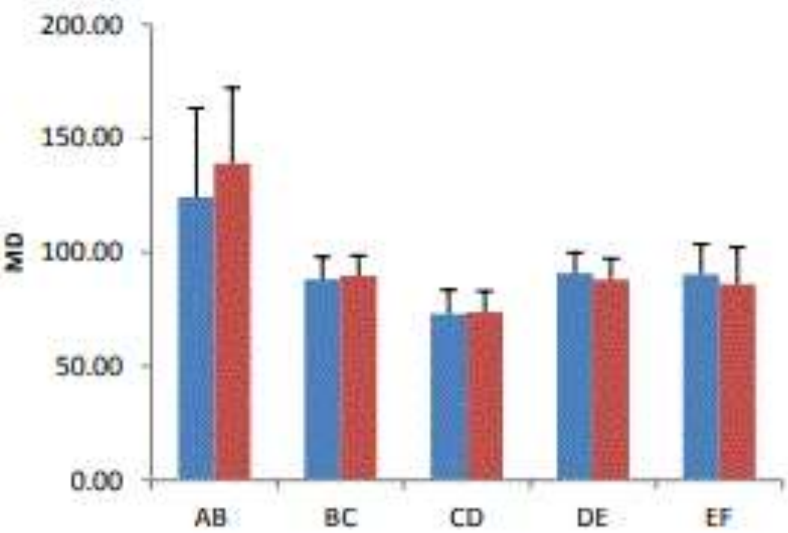

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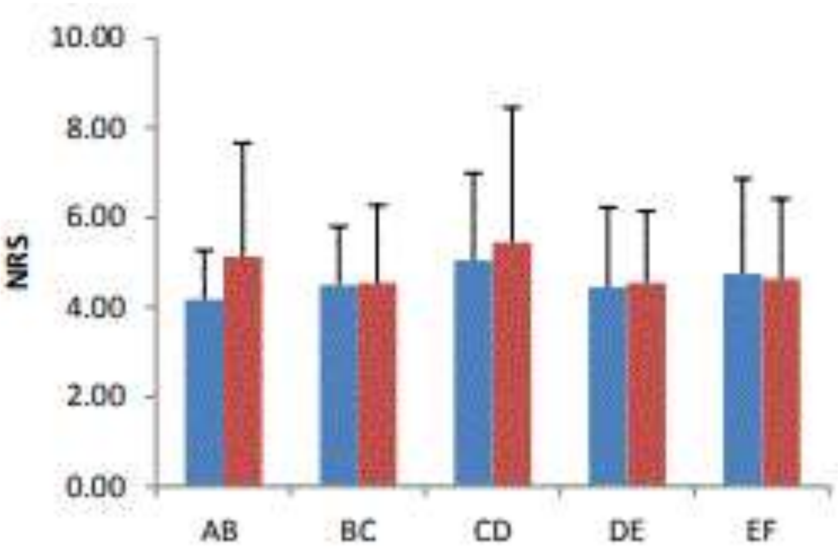

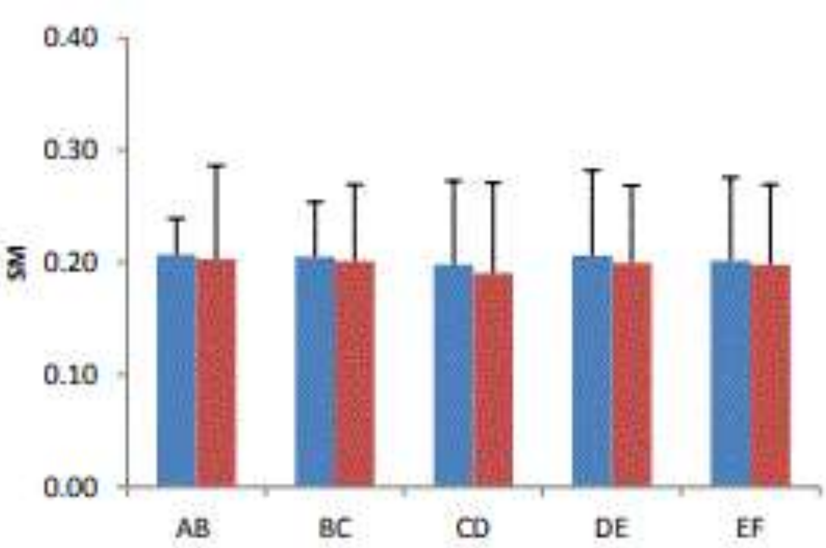

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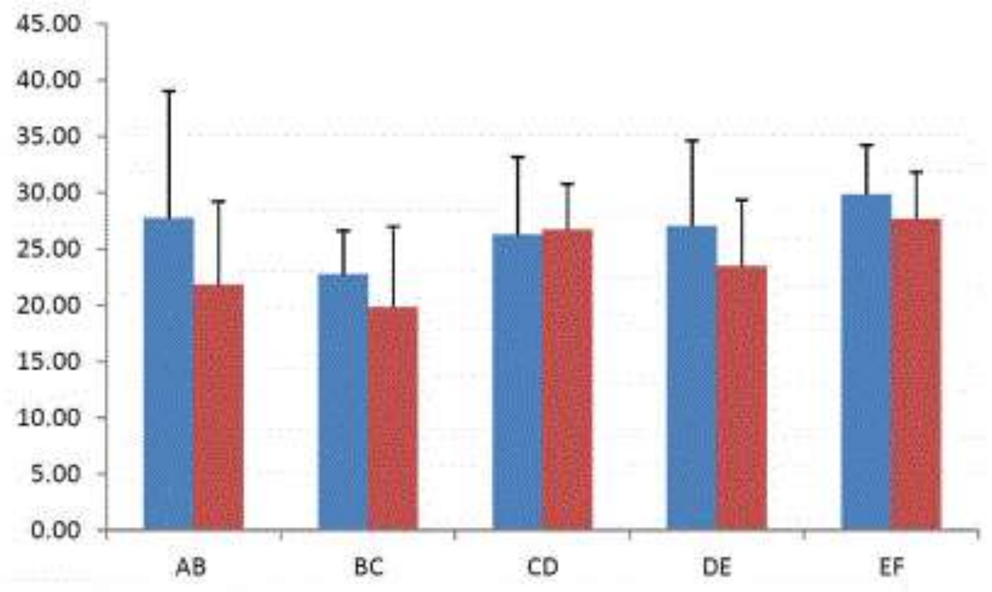
RIABILITAZIONE AUXILIUM VITAE VOLTERRA
di riferimento Regionale

Stefano Mazzoleni

Elena Battini

Normalized jerk



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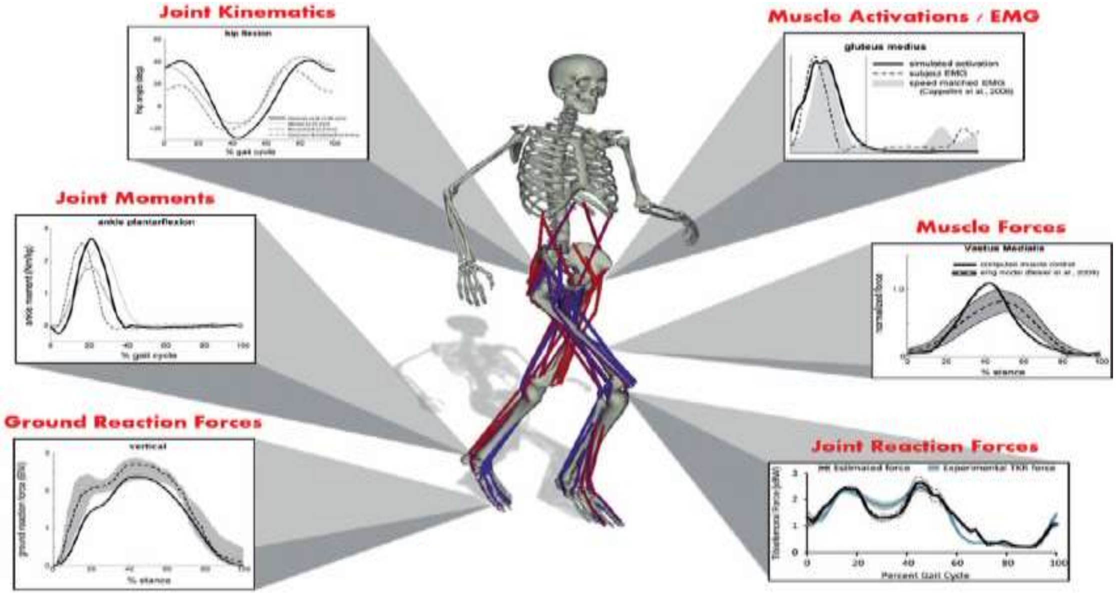
Biomechanical model of the musculoskeletal systems

Stefano Mazzoleni

Vi Do Tran

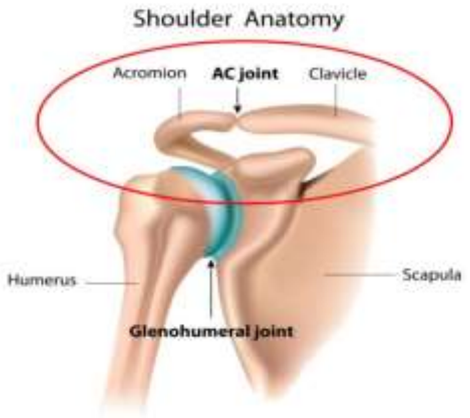
The **biomechanical model** is applied to musculoskeletal rehabilitation to study:

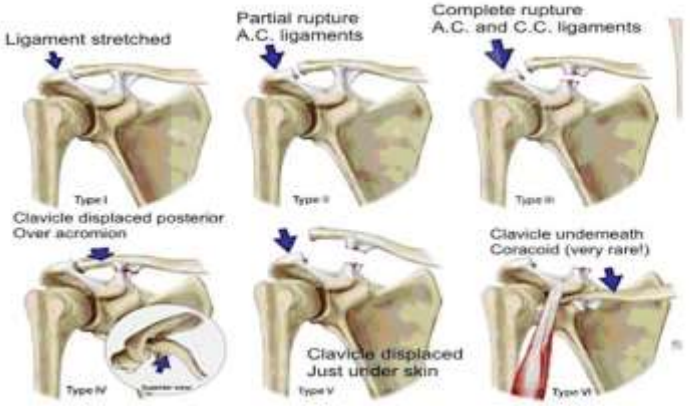
- Kinematics properties of the human joint system.
- Mechanical and biological factors affecting the human skeletal system.
- Muscle responses to the external forces and perturbations.



Biomechanical model of the musculoskeletal systems

Stefano Mazzoleni
Vi Do Tran





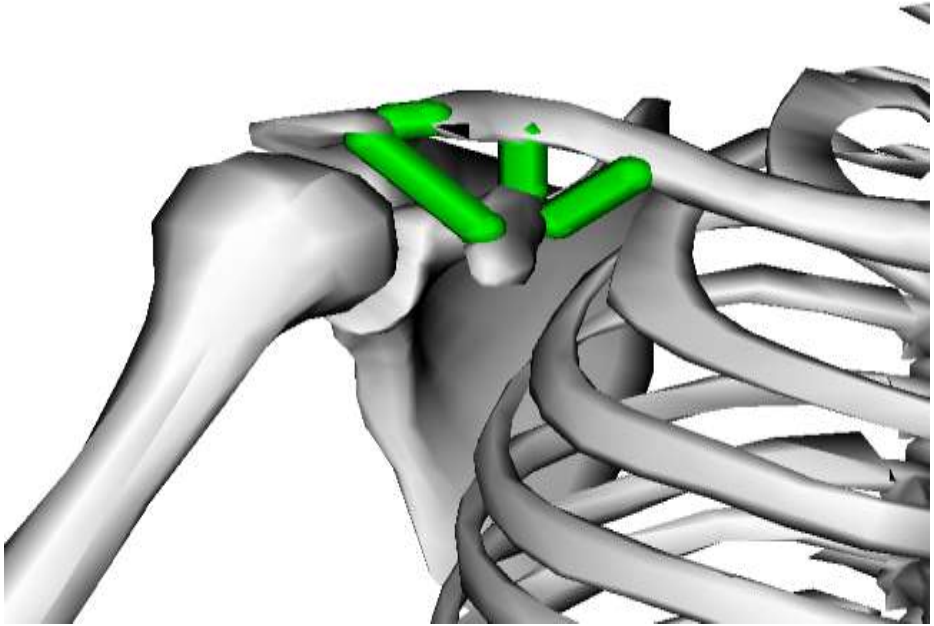
- Develop a model of the upper limb with acromioclavicular joint ligaments to:
  - **Estimate motion kinematics of the shoulder movement** with different types of Rockwood acromioclavicular dislocation
  - **Evaluate the recovery** of the patient after acromioclavicular ligaments surgery
- **Direct application** of musculoskeletal models to rehabilitation

Upper limb biomechanical model

Stefano Mazzoleni

Vi Do Tran

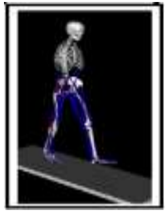
- The model was developed by using OpenSim platform from the dynamic model of upper limb
- The trapezius muscle was added to control the moving, rotating, and stabilizing the scapula
- The acromioclavicular joint ligaments are modelled



Katherine R. Saul, Xiao Hu, Craig M. Goehler, Meghan E. Vidt, Melissa Daly, Anca Velisar & Wendy M. Murray (2014): Benchmarking of dynamic simulation predictions in two software platforms using an upper limb musculoskeletal model, Computer Methods in Biomechanics and Biomedical Engineering

The OpenSim muscle-driven simulation workflow

Scale → Inverse kinematics (IK) → Residual reduction Algorithm (RRA) → Computed muscle control (CMC) → Forward dynamics

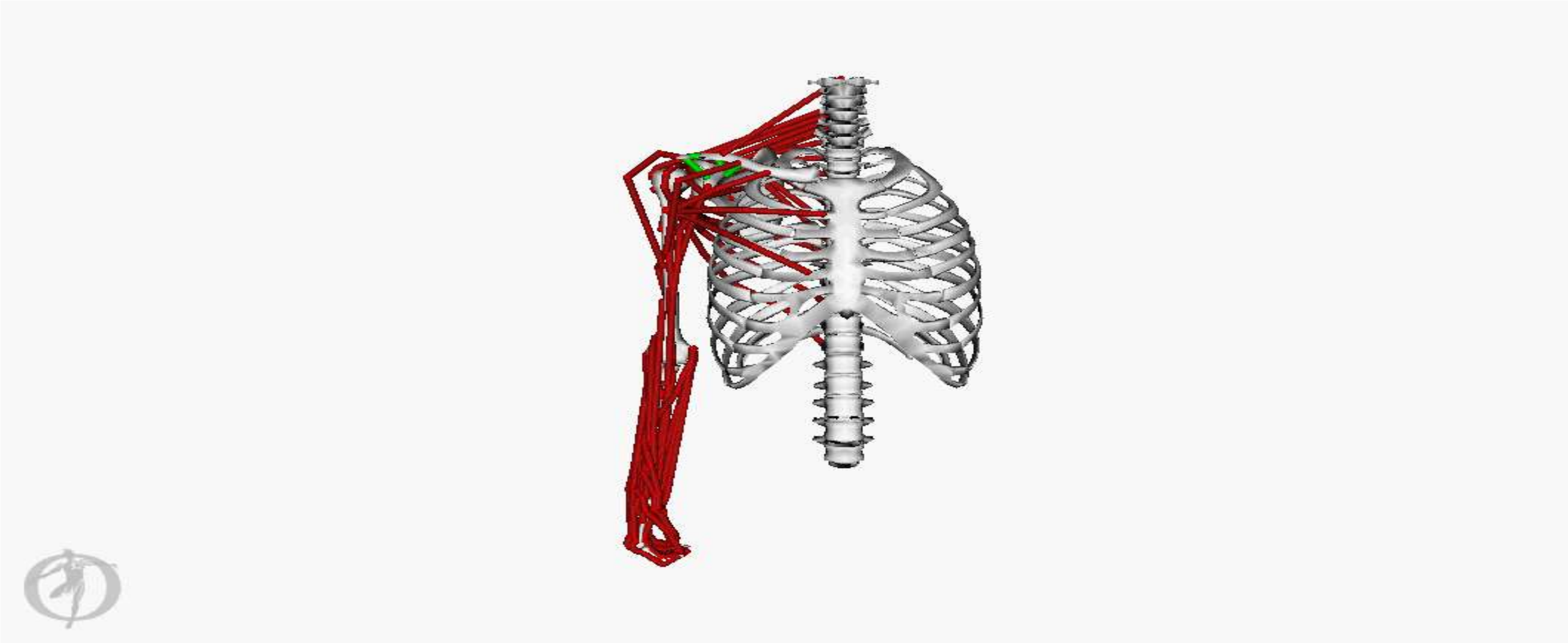


The body landmarks to be recorded:

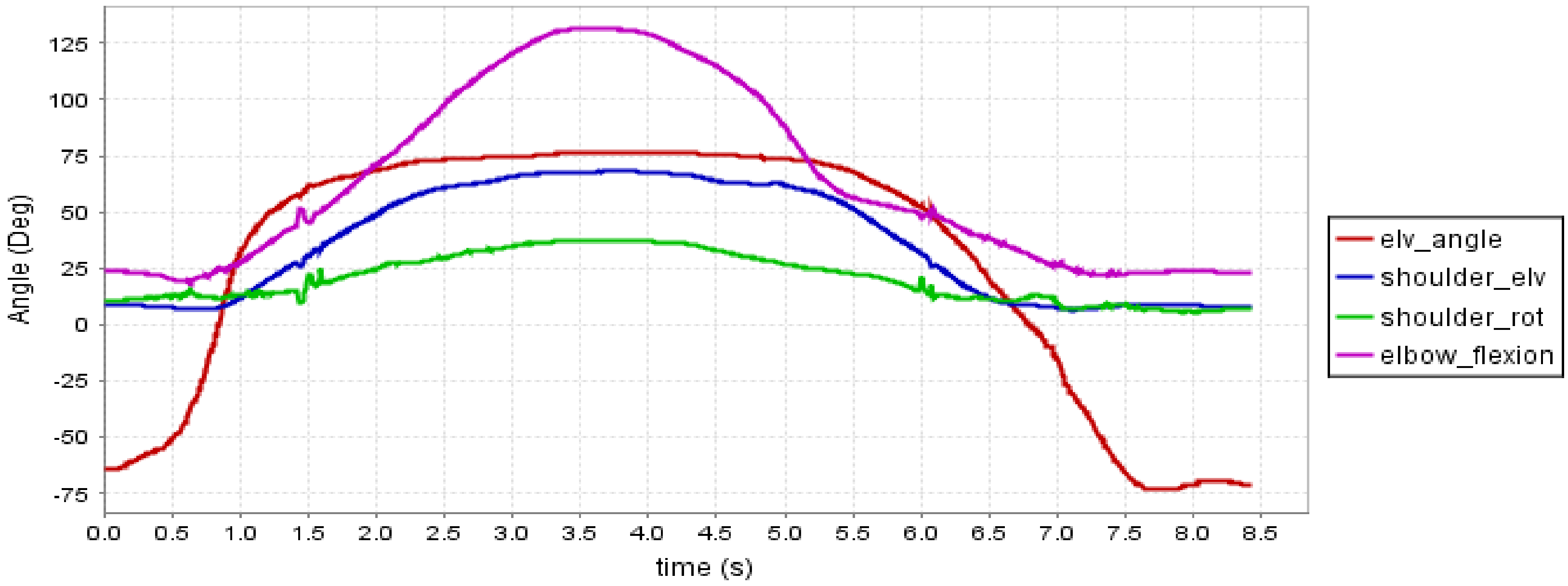
- Torso: acromion, clavicular, C7.
- Right upper arm: bicep front, elbow lateral, elbow medial.
- Right lower arm: wrist lateral, wrist medial and hand

The subject performed a “hand to mouth” movement five times with a self-paced velocity

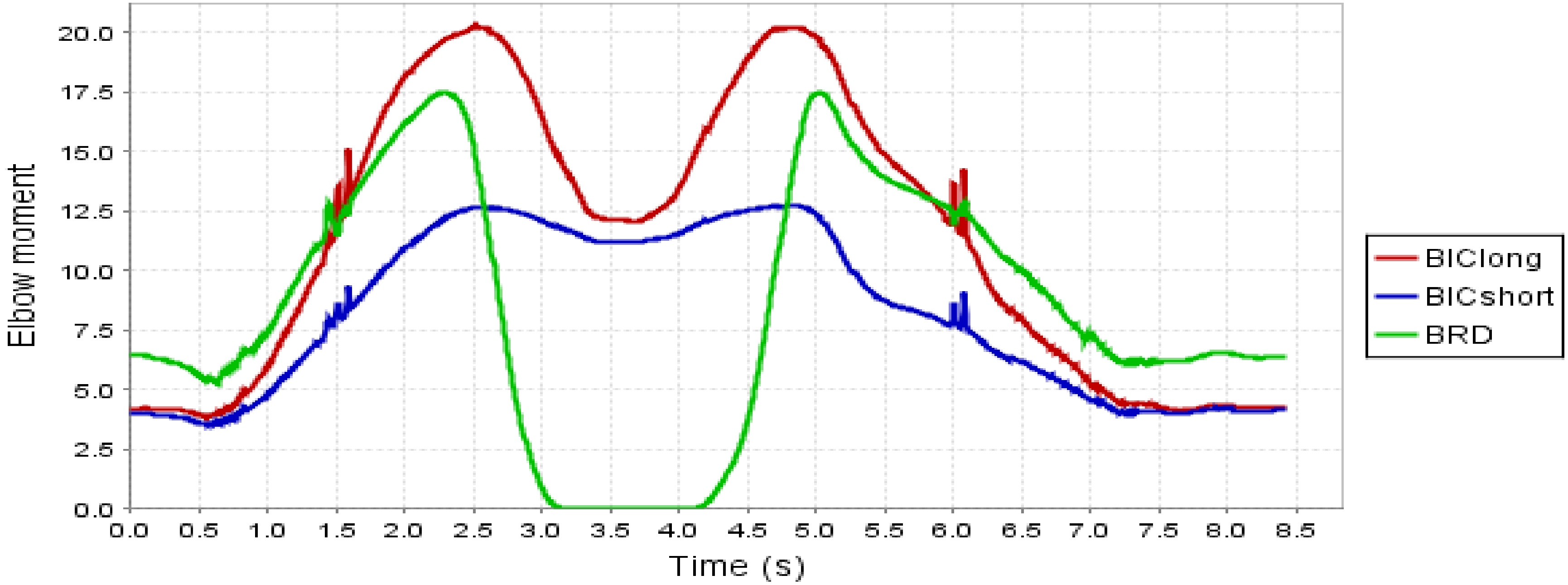
The movements were recorded by a motion capture system (SMART-DT, BTS Bioengineering Corp., Milano, Italy)



Hand-to-mouth movement



Trajectories of DOFs angles during a representative trial



Contribution of muscles to elbow moment (BIClong: biceps brachii long head, BICshort: biceps brachii short head, BRD: brachioradialis)

Outline of the presentation

- BioRobotics and Bionics convergence
- Rehabilitation and Assistive Robotics
  - Upper limb robot-assisted therapy
  - Gait robot-assisted therapy
  - Precision orthopaedic surgery - Precision orthopaedic rehab
  - RISE robotic wheelchair
- Sports biomechanics
- Lessons, new scenarios and challenges

ISTITUTO DI BIOROBOTICA
Sant'Anna

Robotic devices for robot-assisted lower limb rehabilitation: a quick evolution

1999,Volketswil Switzerland LokomatPro

Hocoma

REX BIONICS

Rex Bionics founded in **2003**,

2010, Quebec, Canada, **PROWLER**

b-temia

AGAINER

2010,Riga, USA, **AGAINER SYSTEM**

2010, Ankara, Turkey, **ROBOGAIT**

AXO SUITS

2013, Oradea, Romania, **Axosuit**

DSME

2013, Seoul, South Korea **PROWLER**

ReWalk Robotics

FDA certified June 2014 Observed in 2016

1999 | **2006** | **2008** | **…** | **2012** | **2013** | **2014** | **2015** | **2016**

ALTER G

2005, Freemont, USA, **Bionic LEG**

RB3D we multiply your capacity

2001, Auxere, France **HERCULE**

FDA approval is pending. CE Mark certified 2006

HONDA The Power of Dreams

2010, Japan **Stride Management and Bodyweight Support Assist**

FDA certified 2012

BIONIK LABORATORIES

2013,Toronto, Canada, **ARKE** FDA approval expected in 2017

EXOATLET

2013,Moscu, Russia, **EXOATLET**

2014, Ottawa – Canada, **MODO**

FDA certified 2016

Parker

Robot-assisted gait rehabilitation for Spinal Cord Injured (SCI) patients


Stefano Mazzoleni


Elena Battini

Robot-assisted treadmill gait training

Robot-assisted overground gait training

FES-cycling

FES during *walking*

Robot-assisted rehabilitation for SCI patients: FES-cycling

Stefano Mazzoleni

Elena Battini

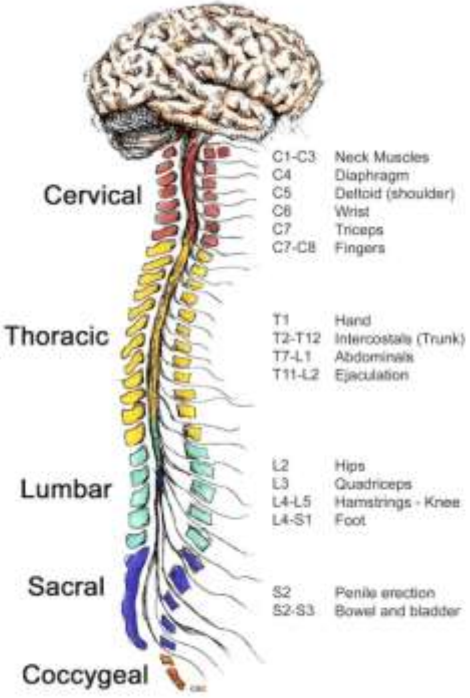
Background

The **loss of mobility** following spinal cord injury (SCI) negatively affects the health status of life of patients. In addition other physical complications, such as **muscular atrophy**, **muscular spasticity**, **reduction of cardio-respiratory capacity and pain**, often occur as well .

The improvement of bone, muscular and joint trophism and the reduction of spastic hypertone represent relevant aims to be achieved during SCI rehabilitation.

The Functional Electrical Stimulation (FES) causes an electrically driven contraction, that differs from a physiological contraction in terms of action potential and in terms of number and type of recruited motor units, which progresses from large to small. (reference FES)

The benefits of FES were demonstrated since the 80s: improvements obtained in cardiovascular and respiratory functions (R. Martin *et al.* 2012), body composition , muscle mass , bone mass and quality of life .



Aim

to use FES to activate pedaling on cycle-ergometer and analyse the effects of this technique for a rehabilitation training in SCI persons

S. Mazzoleni,. G. Stampacchia., A. Gerini, T. Tombini, MC Carrozza. FES-cycling training in Spinal Cord Injured patient. Conf Proc IEEE Eng Med Biol Soc. 2013;2013:5339-41.
R. Martin, C. Sadowksy, K, Obst, *et al.* Functional electrical stimulation in spinal cord injury: from theory to practice. *Top Spinal Cord Inj Rehabil*, 18(1): 20-33, 2012.

Robot-assisted rehabilitation for SCI patients: FES-cycling approach

Stefano Mazzoleni

Elena Battini

Methods

Five subjects complete and incomplete spinal cord injured (SCI) subjects (mean age 43.0±11.8, four men and one woman)
20 sessions three times per week.

Clinical assessment

was carried out before starting the treatment (T0), at mid-treatment (T1), after 10 sessions, and at the end of the treatment (T2).

- ASIA,
- SCIM,
- Modified Ashworth Scale (MAS)
- 4-point Spasms Scale evaluati
- thigh circumference at 5 (A), 10 (B) and 15 (C) cm

from the knee cap upper limit.

ID	*Gender*	*Age*	*ASIA*	*Lesion level*	*SCIM*
P1	M	50	C	C7	53
P2	F	42	B	T10	68
P3	M	44	A	T12	71
P4	M	24	B	C7	56
P5	M	55	C	T12	70

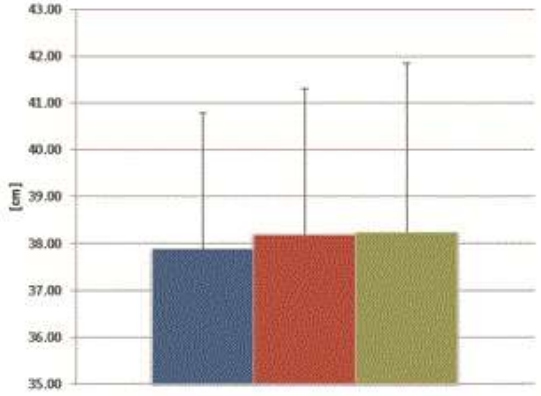
S. Mazzoleni,. E. Battini, A. Rusitci, and G. Stampacchia. An integrated gait rehabilitation training based on Functional Electrical Stimulation cycling and overground robotic exoskeleton in complete spinal cord injury patients: preliminary results. 2017 International Conference on Rehabilitation Robotics (ICORR) 2017.

Robot-assisted rehabilitation for SCI patients: FES-cycling approach

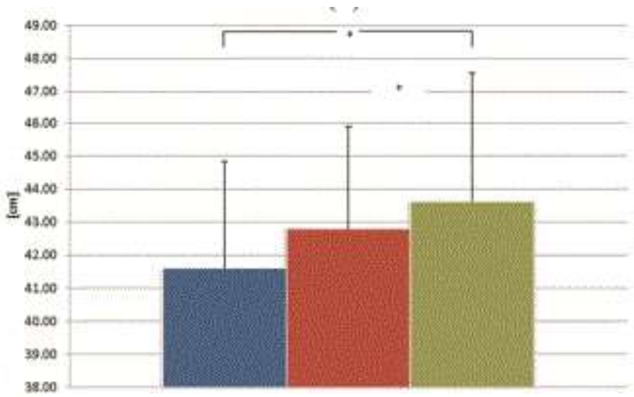
Stefano Mazzoleni

Elena Battini

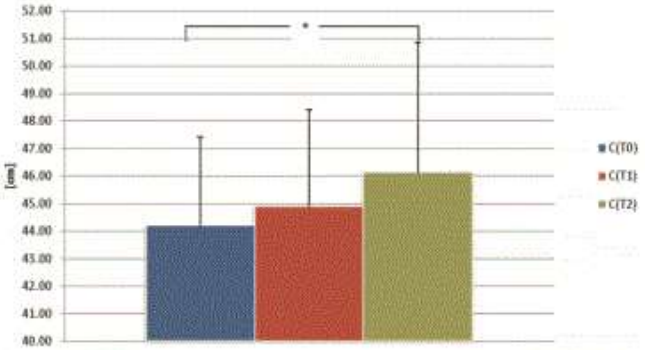
Results: thigh circumference



5 cm from kneecap



10 cm from kneecap



15 cm from kneecap

S. Mazzoleni,. E. Battini, A. Rusitci, and G. Stampacchia. An integrated gait rehabilitation training based on Functional Electrical Stimulation cycling and overground robotic exoskeleton in complete spinal cord injury patients: preliminary results. 2017 International Conference on Rehabilitation Robotics (ICORR) 2017.

Robot-assisted rehabilitation for SCI patients: preliminary results of FES-cycling approach and a novel Effectiveness Index proposal


Stefano Mazzoleni
Elena Battini

Aims:

- to **propose** and **validate a novel effectiveness index (EI)** based on the mechanical power recorded during the FES-cycling training;
- to **analyse the energy expenditure** (EE) during the entire rehabilitation period in a group **of complete SCI patients** by using the power recorded during the rehabilitation session by using only the FES-cycling system.

Methods:

- 24 chronic complete SCI patients (20 men, mean age: 39.42 ± 11.26 , range: 22-66, n=14 ASIA A, n=10 ASIA B)
- N=20 sessions of FES-cycling training
- 8 healthy subjects for comparison purposes

Inclusion criteria

- age ≥ 18;
- motor complete spinal cord injury, both traumatic and not-traumatic.

Exclusions criteria

- severe joint limitations that prevent the use of FES-cycling;
- total denervation that prevents the use of FES-cycling.

ID	Gender	Age	ASIA	Lesional level	Cause of lesion	SCIM
P1	F	26	A	D8	T	67
P2	M	39	A	D5	T	73
P3	M	22	B	C6	T	48
P4	M	24	C	C6	T	52
P5	M	48	A	D12	T	72
P6	F	42	B	D5	T	57
P7	M	40	A	D3	T	73
P8	M	47	B	D10	T	72
P9	M	26	A	D12	T	66
P10	M	48	A	D5	T	67
P11	M	43	B	D8	T	61
P12	M	26	B	C7	T	62
P13	M	29	B	D12	T	71
P14	F	46	A	D9	T	61
P15	M	25	A	D12	T	64
P16	M	46	A	D6	T	76
P17	F	27	B	T12	NT	23
P18	M	44	A	L1	T	79
P19	M	40	B	T4	T	60
P20	M	43	B	C6	NT	34
P21	M	49	B	D11	T	77
P22	M	45	A	D6	T	54
P23	M	62	A	D6	NT	22
P24	M	59	B	T12	T	72

Unpublished data

Robot-assisted rehabilitation for SCI patients: preliminary results of FES-cycling approach and a novel Effectiveness Index proposal

Stefano Mazzoleni

Elena Battini

Assessment otucome measures:

- American Spinal Injury Association scale (ASIA)
- Spinal Cord Independence Measure Scale (SCIM)
- Penn Spasms Frequency Scale (PSFS)
- Modified Ashworth Scale (MAS)
- Numerical Rating Scale (NRS)
- Power generated
- **Energy expenditure**
- **Efficiency Index**

$$EI(\%) = \left(\frac{P_{max} - P_{final}}{P_{max}} \right) x100$$

20 FES-cycling training sessions

Robot-assisted rehabilitation for SCI patients: preliminary results of FES-cycling approach and a novel Effectiveness Index proposal


Stefano Mazzoleni
Elena Battini

FES-cycling parameters:

(i) stimulation frequency f=50 Hz,
(ii) square biphasic alternated wave,
(iii) duration of pulse (pulse width) of 500 µs,
(iv) duty cycle (e.g., the ratio of the time when the stimulation wave is active and the time when it is inactive) of 50%.

The current amplitude represents the delivered stimulation intensity (FES-cycling range amplitude: 0-140 mA).

The target speed is the objective speed set by the therapist (range: 10-70 rpm) and it represents the speed to be reached during the session. In this study the target speed was set at 35 rpm.

The resistance level represents the resistance opposed by the FES-cycling motor. In this study this value was constant and equal to 5.00 Nm.

Robot-assisted rehabilitation for SCI patients: preliminary results of FES-cycling approach and a novel Effectiveness Index proposal

Stefano Mazzoleni

Elena Battini

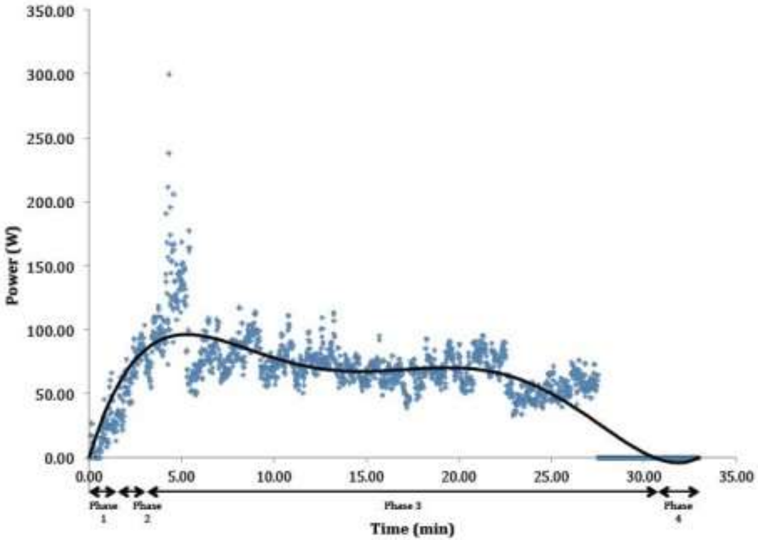
Data interpolation was performed using custom routines implemented under the Matlab environment (The MathWorks Inc., Natick, USA). Three different interpolation functions and different orders (n) were tested:

(i) polynomial (3 ≤ n ≤7),

(ii) sum of sine (3 ≤ n ≤5)

(iii) exponential functions as sum function of two terms.

Type	n	T0	T1	T2
Polynomial	3	0.379	0.319	0.346
	4	0.338	0.333	0.416
	5	0.378	0.312	0.346
	6	0.404	0.333	0.387
	7	0.414	0.325	0.405
Sum of sine	3	0.268	0.244	0.269
	4	0.357	0.322	0.329
	5	0.333	0.313	0.366
Exponential	2	0.341	0.304	0.309



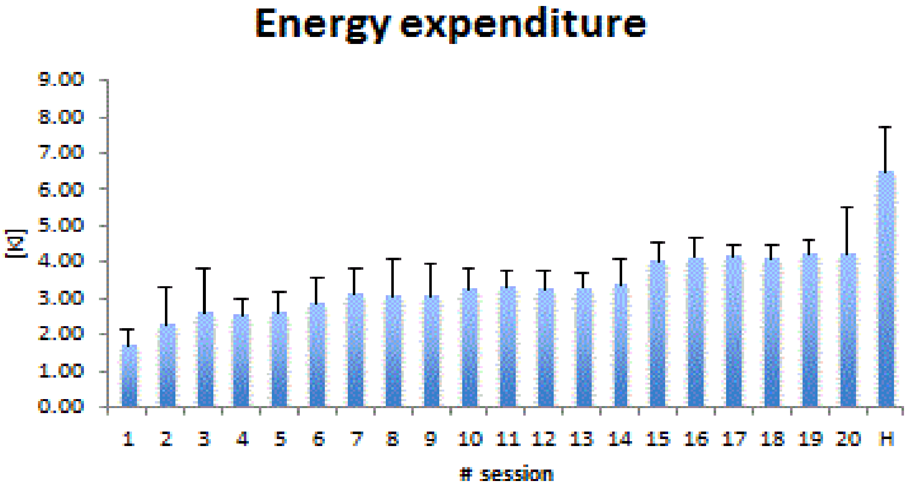
Unpublished data

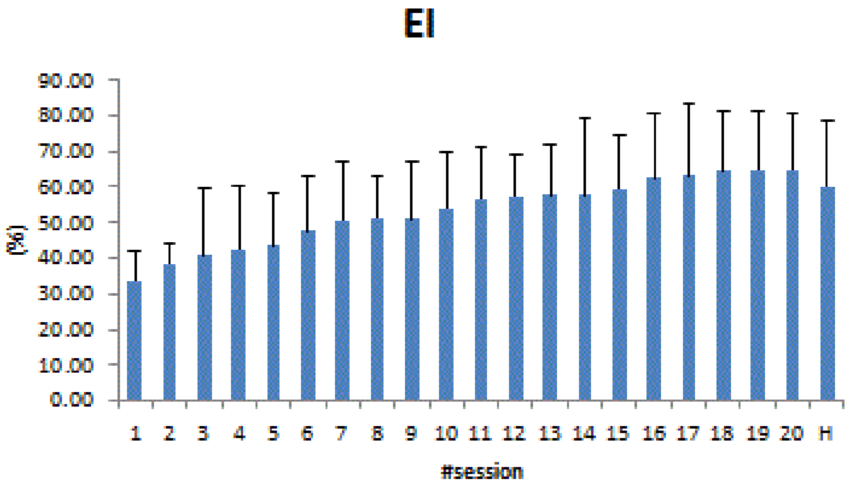
Robot-assisted rehabilitation for SCI patients: preliminary results of FES-cycling approach and a novel Effectiveness Index proposal

Stefano Mazzoleni

Elena Battini

Results





$$EI(\%) = \left(\frac{P_{max} - P_{final}}{P_{max}} \right) x100$$

Unpublished data

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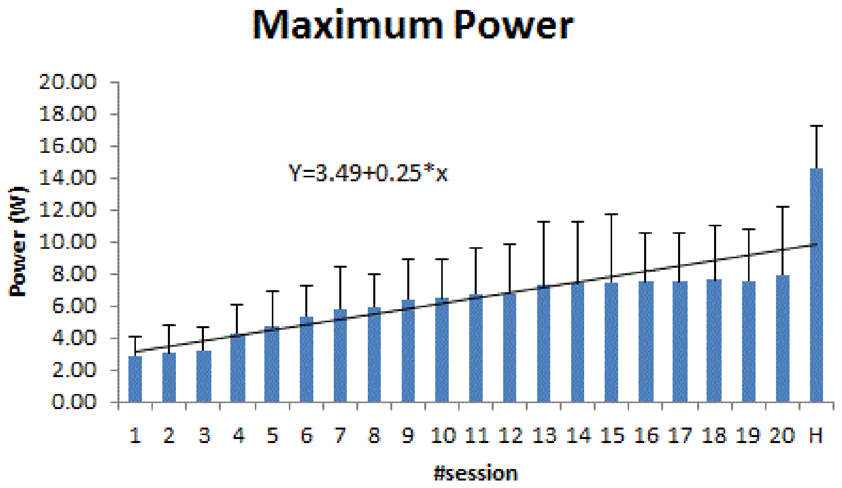
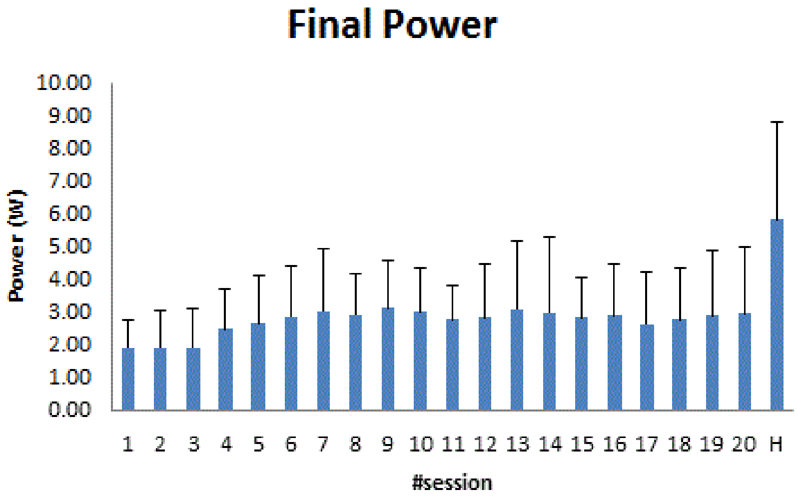




Unpublished data

Robot-assisted treadmill gait rehabilitation for SCI patients: Surface EMG measurements and analysis


Stefano Mazzoleni


Elena Battini

	SCIM		WISCI-II	
ID	Pre-training	Post-training	Pre-training	Post-training
1 (SCI)	13	25	0	8
2 (SCI)	34	37	0	0
3 (MS)	11	21	0	7
4 (MS)	76	78	14	16
5 (MS)	80	82	14	15
6 (MS)	50	50	1	1
7 (SCI)	75	75	9	9

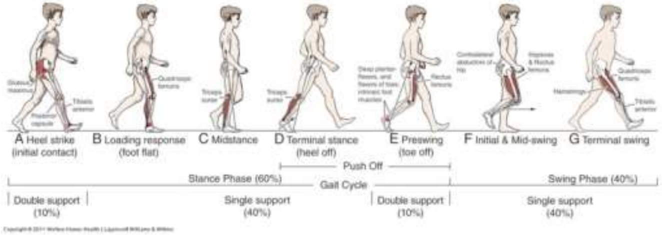
The **aim** of this study is to **evaluate the effects of robot-assisted locomotor training** on **muscular recruitment** in patients with gait disorders.

Patients enrollment:
- 7 subjects (5 M, 2 F, mean age 53.7±14.7, range 23-67)
- 3 SCI patients
- 4 Multiple Sclerosis (MS) patients
- 5 control subjects (4 M, 1 F, mean age 35.8 ± 17.6, range 18-57)

EMG recording
- rectus femoris (**RF**) and biceps femoris (**BF**) of both legs
- two treadmill speeds (v_1 = **1.0 km/h**, v_2 = **2.0 km/h**)
- two robot-interaction modalities (**passive and active)**

EMG Data Analysis
- Rectification
- Signal processing
- Signal filtering
- Signal normalization
- Integration

$$IEMG_1 = \int_{t_1}^{t_2} sEMG^*(t)dt \qquad IEMG_2 = \int_{t_3}^{t_4} sEMG^*(t)dt$$



S. Mazzoleni, E. Battini, T. Tombini, G. Stampacchia. "Effects of robot-assisted locomotor training in patients with gait disorders following neurological injury: an integrated EMG and kinematic approach", in Proc. 14th IEEE/RAS-EMBS International Conference on Rehabilitation Robotics, August 11-14, 2015, Singapore, pp. 775-779

Robot-assisted treadmill gait rehabilitation for SCI patients: Surface EMG measurements and analysis

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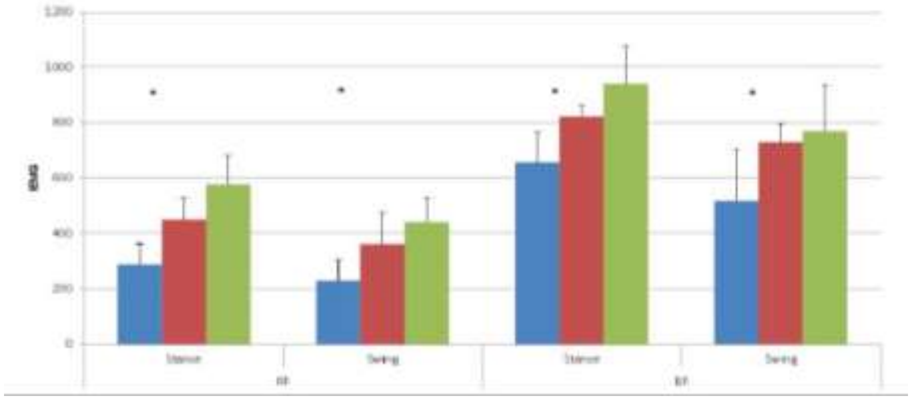
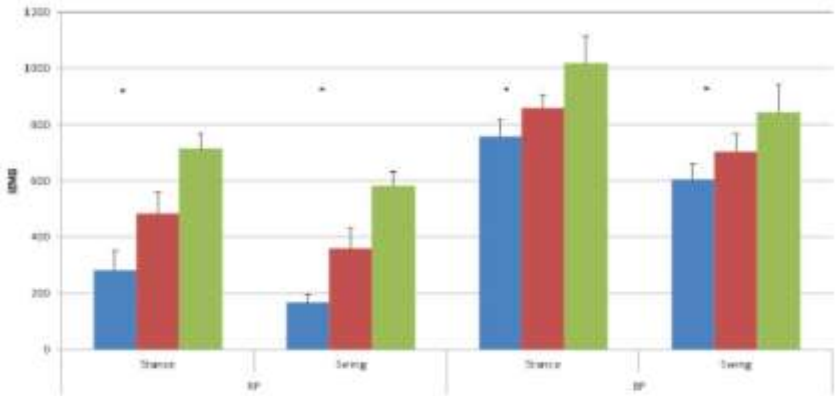
DGO active, v_1



DGO active, v_2



blue, patients pre-treatment; red, patients post-treatment; green: healthy subjects

	v_1		v_2	
	Stance	Swing	Stance	Swing
RF	55.55	58.49	71.51	114.41
BF	25.39	41.12	13.63	16.43

S. Mazzoleni, E. Battini, T. Tombini, G. Stampacchia. "Effects of robot-assisted locomotor training in patients with gait disorders following neurological injury: an integrated EMG and kinematic approach", in Proc. 14th IEEE/RAS-EMBS International Conference on Rehabilitation Robotics, August 11-14, 2015, Singapore, pp. 775-779

Robot-assisted overground gait rehabilitation for SCI patients: subjective experience


Stefano Mazzoleni


Elena Battini

Aim

• to investigate the **acceptability of oveground robot-assisted walking** and its effects on pain and spasticity

Methods

• **21 Spinal Cord Injury** (SCI) patients (17 men, 4 women; mean age: 48.10±1.23)
• **Single session** using powered robotic exoskeleton (Ekso GT, Ekso Bionics, USA)

Assessment measures

• Pain and muscle spasticity assessed using Numerical Rating Scale (**NRS-pain** and **NRS-spasticity**). Muscle spasticity was also evaluated using Modified Ashworth Scale (**MAS)** and Penn Spasm Frequency Scale (**PSFS)**
• Positive and negative sensations were investigated using an apposite questionnaire
• PSFS, NRS-pain and NRS-spasticity scores were analysed using repeated measures ANOVA

G. Stampacchia, A. Rustici, S. Bigazzi, A. Gerini, T. Tombini and **S. Mazzoleni**. Walking with a powered robotic exoskeleton: subjective experience, spasticity and pain in spinal cord injured persons. NeuroRehabilitation 39 (2016), 277-3283

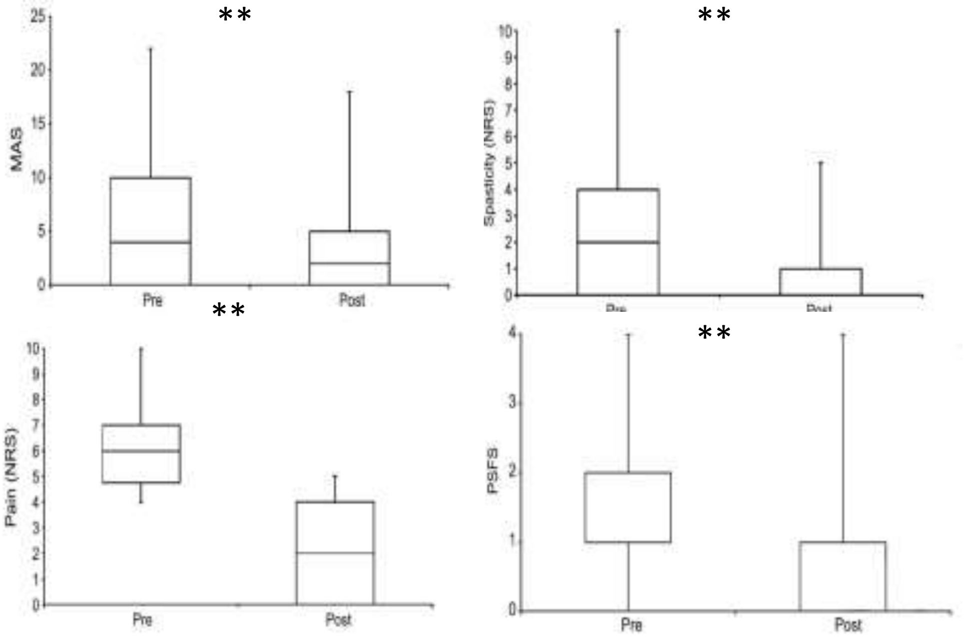
Robot-assisted overground gait rehabilitation for SCI patients: subjective experience

Stefano Mazzoleni

Elena Battini

#ID	Age	Gender	Cause of lesion	Time from acute event (months)	ASIA	Lesion level	WISCI II	SCIM II
P1	46	M	T	37	A	D9	0	72
P2	44	F	T	60	A	D10	0	61
P3	43	M	T	12	A	D3	0	61
P4	57	M	T	54	B	D12	0	72
P5	55	M	T	125	A	D12	0	72
P6	44	M	T	330	A	D6	0	76
P7	60	F	NT (ischemic)	29	D	L1	9	75
P8	21	M	NT (tumor)	38	A	D9	0	71
P9	43	M	T	218	A	L1	0	79
P10	48	M	T	31	D	D12	0	71
P11	25	M	NT (ischemic)	2	D	L2	1	63
P12	46	M	T	294	A	D6	0	67
P13	42	M	NT (tumor)	300	B	C7	0	34
P14	45	M	T	165	A	D3	0	62
P15	56	M	T	153	A	D7	0	68
P16	38	M	T	119	A	D4	0	73
P17	68	M	NT (degenerative)	59	D	L1	0	54
P18	58	M	T	30	A	D4	0	53
P19	40	M	T	225	D	C7	16	79
P20	63	F	NT (degenerative)	69	D	C7	6	52
P21	68	F	NT (tumor)	227	D	C7	19	65

Legend: T, traumatic; NT, non-traumatic.



G. Stampacchia, A. Rustici, S. Bigazzi, A. Gerini, T. Tombini and **S. Mazzoleni**. Walking with a powered robotic exoskeleton: subjective experience, spasticity and pain in spinal cord injured persons. NeuroRehabilitation 39 (2016), 277-3283

Robot-assisted gait rehabilitation for SCI patients: driven gait orhosis vs overground powered exoskeleton


Stefano Mazzoleni


Elena Battini

Hypothesis:

Is there any difference in terms of **MET and VO_2 consumption** between driven gait orthosis and overground exoskeleton training?

Methods:

- 8 SCI subjects, mean age: 45.38 ±15.26, mean time from pathology onset: 60.88 ± 103.41 months;
- Patients underwent a robot-assisted gait exercise using two different robotic systems: an **overground robotic exoskeleton** (Ekso GT, Ekso Bionics, USA) (modality 1) and a **driven gait orthosis** (Lokomat, Hocoma, Switzerland) (modality 2).
- Measurements were recorded during **a single rehabilitation session**
- **A questionnaire** (6 items, score ranging from 0 to 10) aims **to investigate the subjective perception during the two robot-assisted gait exercises**


modality 1


modality 2

ID	Gender	Age	Cause of lesion	Level of lesion	ASIA
1	M	25	T	L1	A
2	F	26	NT	L2	C
3	M	42	T	L1	B
4	M	44	T	L3	A
5	M	48	T	D11	C
6	F	56	NT	C4	C
7	M	56	NT	D6	D
8	F	64	NT	L2	A

S. Mazzoleni, E. Battini, M.Dini, S. Corbianco, A. Gerini, G. Stampacchia. "Physical and cognitive effort during robotic exoskeleton assisted walking on treadmill and overground in SCI persons", 17th National Congress of Italian Society of Movement Analysis in Clinical setting, 5-8 Ottobre 2016, Milano, Italy.

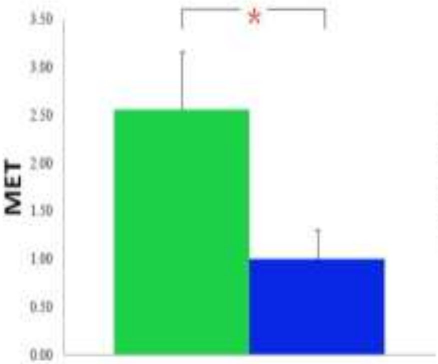
Robot-assisted gait rehabilitation for SCI patients: driven gait orhosis vs overground powered exoskeleton

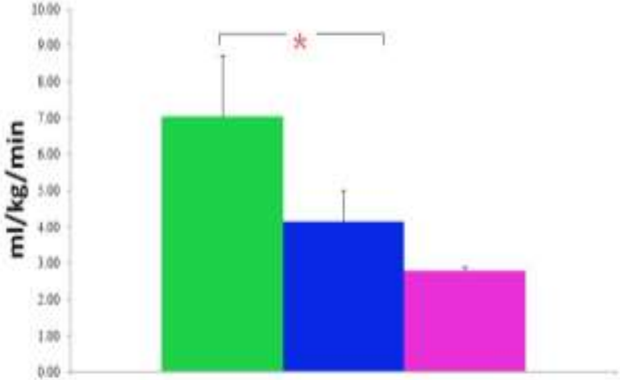

Stefano Mazzoleni

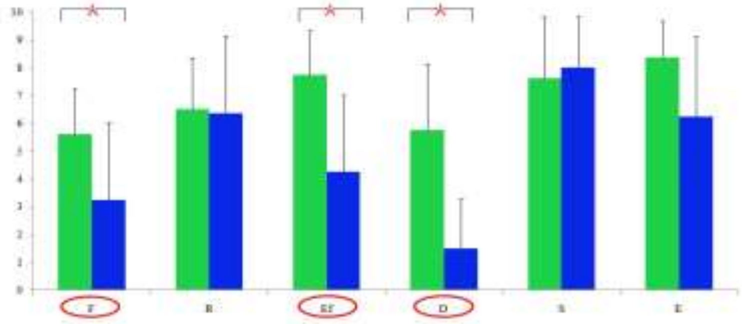
Elena Battini

modality 1

modality 2







Overground (*modality 1*)

Treadmill (*modality 2*)

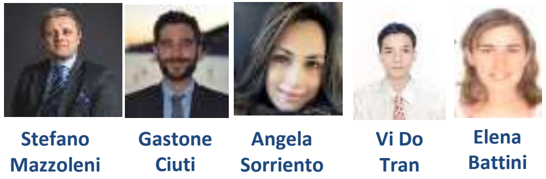
Questionnaire
Fatigue (F)
Muscle relaxation (R)
Mental effort (Ef)
Fear or Discomfort (D)
Satisfaction (S)
Emotion (E)

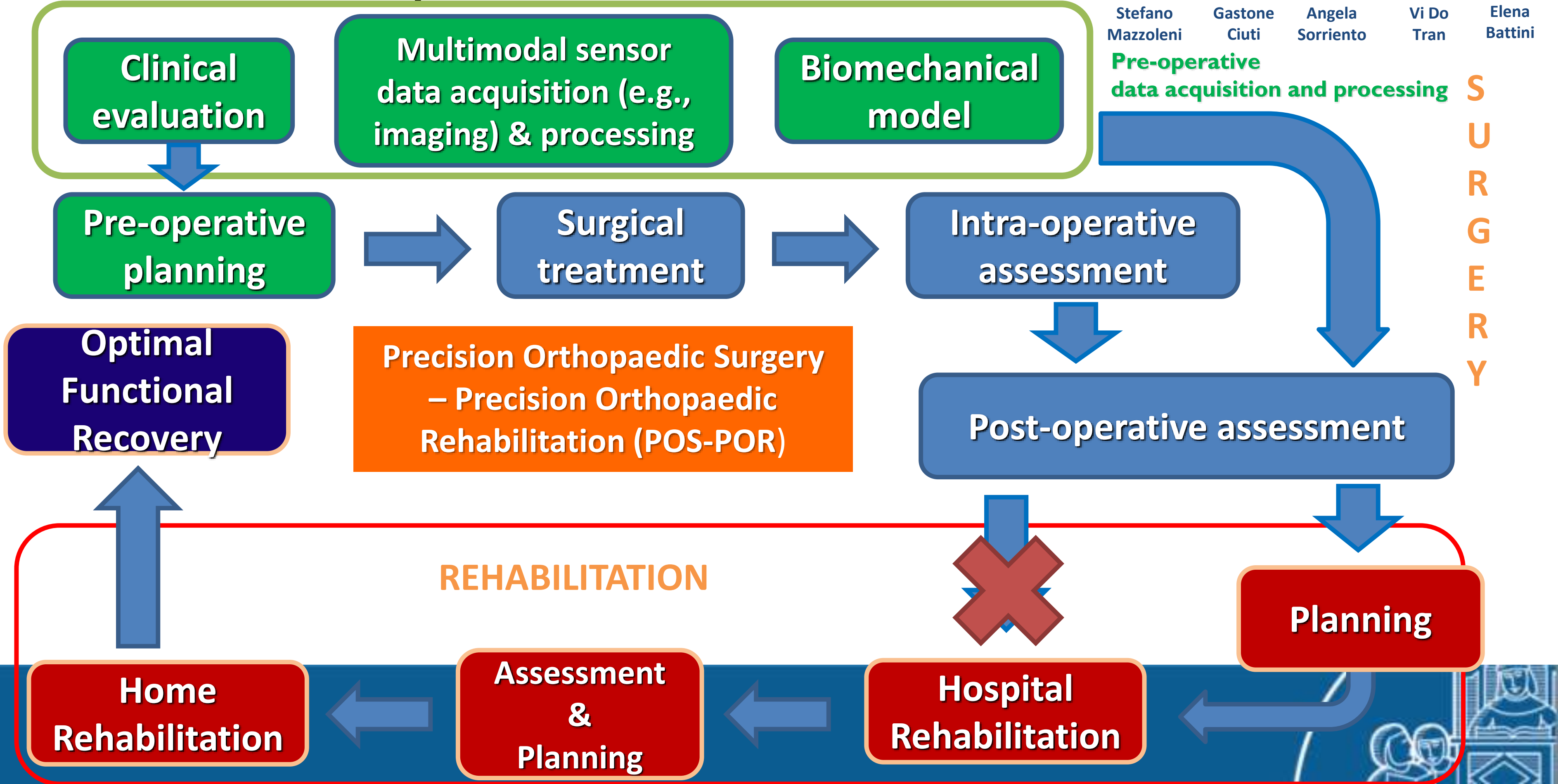
S. Mazzoleni, E. Battini, M.Dini, S. Corbianco, A. Gerini, G. Stampacchia. "Physical and cognitive effort during robotic exoskeleton assisted walking on treadmill and overground in SCI persons", 17th National Congress of Italian Society of Movement Analysis in Clinical setting, 5-8 Ottobre 2016, Milano, Italy.

Outline of the presentation

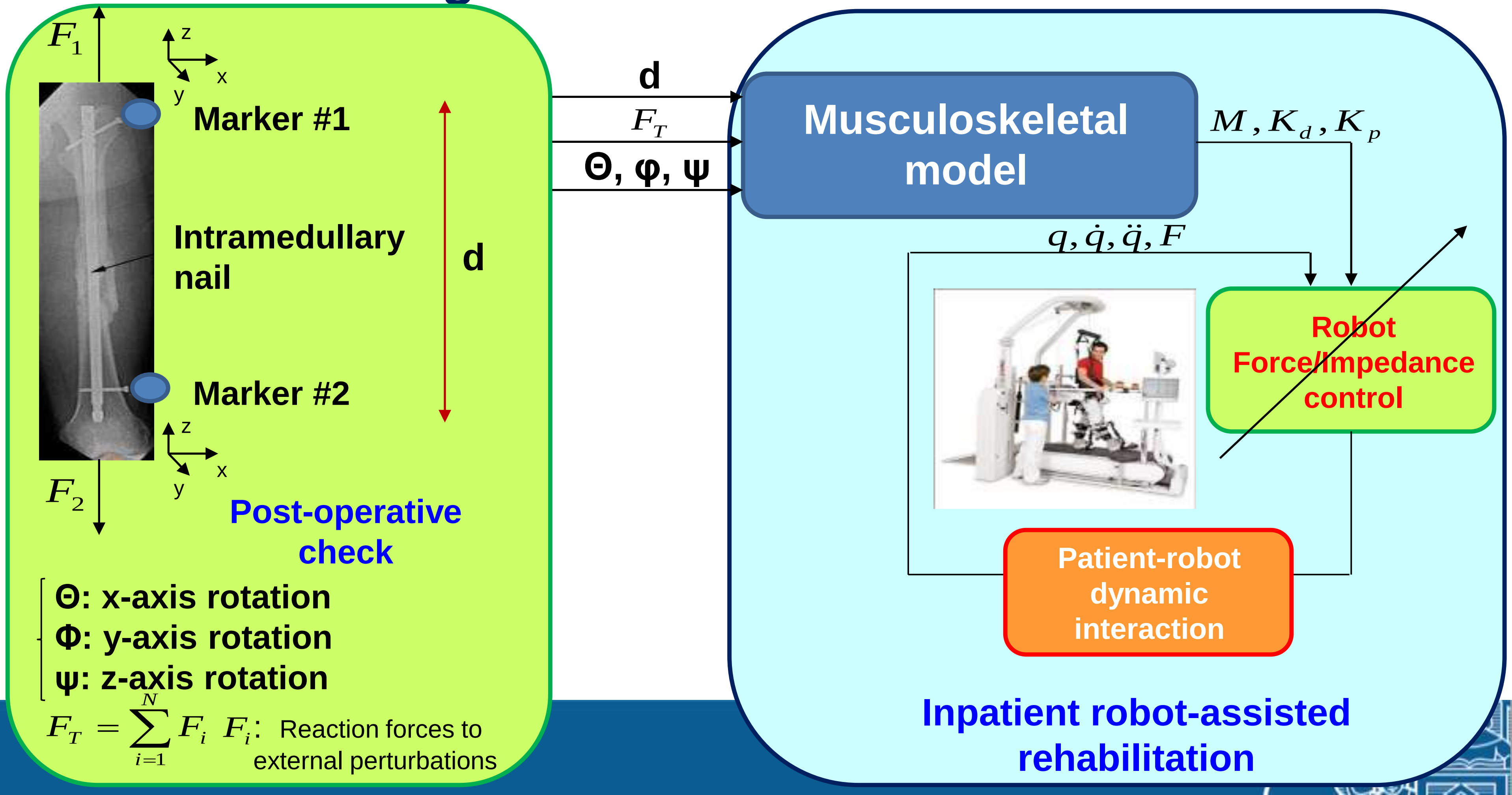
- BioRobotics and Bionics convergence
- Rehabilitation and Assistive Robotics
  - Upper limb robot-assisted therapy
  - Gait robot-assisted therapy
  - Precision orthopaedic surgery - Precision orthopaedic rehab
  - RISE robotic wheelchair
- Sports biomechanics
- Lessons, new scenarios and challenges

A new research line: Precision Orthopaedic Surgery and Precision Orthopaedic Rehabilitation





From surgical intervention to rehabilitation



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INAIL Centro di Riabilitazione Motoria Volterra

Robotic system for verticalisation and mobility of severely impaired persons (2013-2019)

Robotic wheelchair RISE


Stefano Mazzoleni


Elena Battini

Innovative features:

- improved frontal access
- automatic verticalisation
- gluteal-perineal mechanical design for easy toilet access
- mobility (upright and sitting posture)

Clinical validation (end: July 2019) at CRM INAIL Volterra (n=10 persons affected by low-thoracic Spinal Cord Injury)

Patent: “Dispositivo robotico per la verticalizzazione e la mobilità di persone con gravi disabilità” (priority n. 102016000050120)

Mechanical design

T stand-up = 30

Starting position

Actuator A
(1350 N)

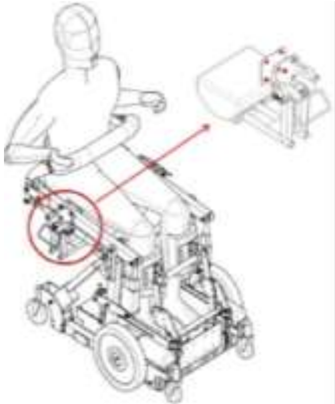
Actuator B
(2450 N)

System for feet adjustable

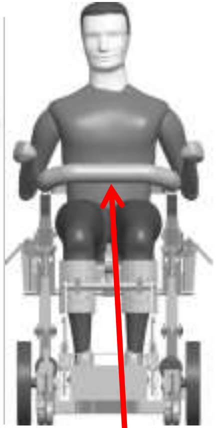
lumbar support

3 interfacce **regolabili**:

- **Thigh interface**
- **Frontal interface**
- **Tibial support**



Thigh interface



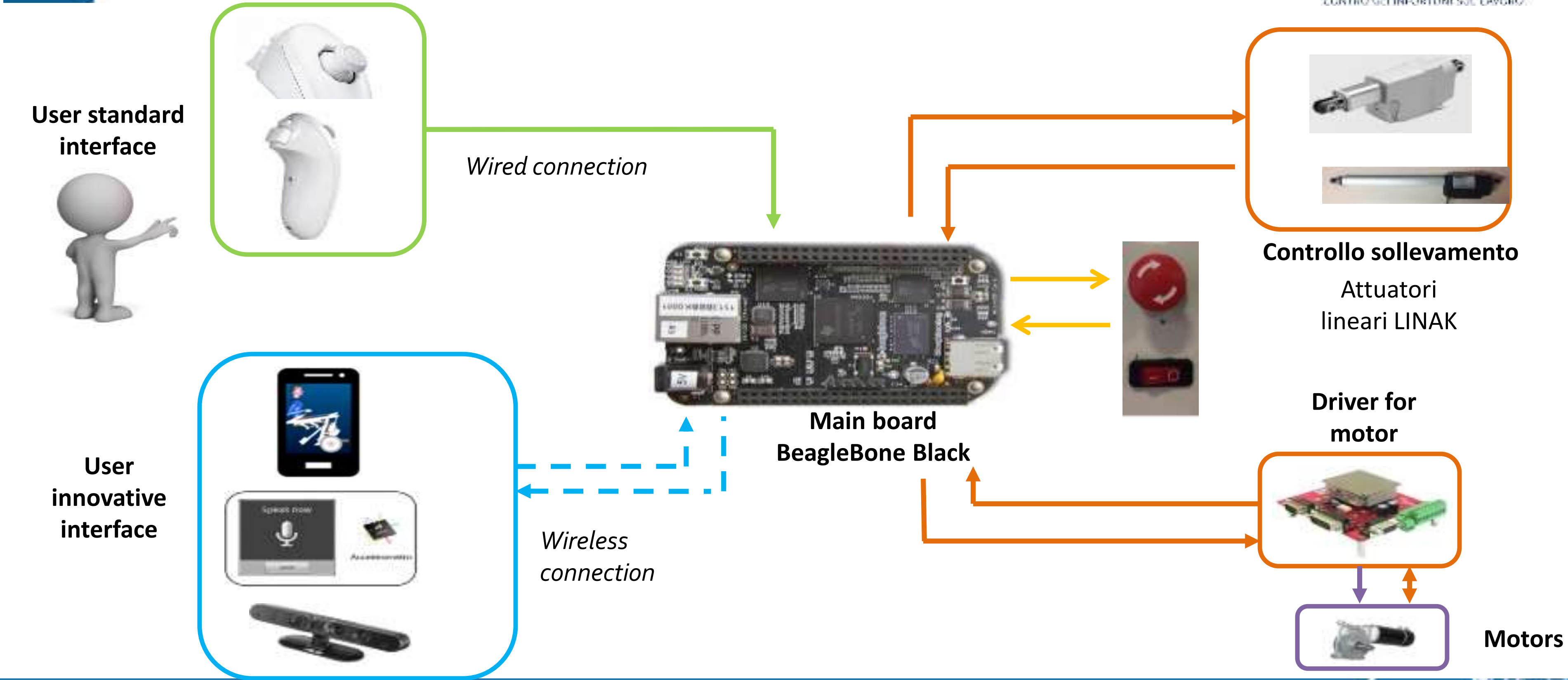
Frontal interface

Tibial support

ISTITUTO DI BIOROBOTICA Sant'Anna

Control design

INAIL
ISTITUTO NAZIONALE PER L'ASSICURAZIONE CONTRO GLI INFORTUNI SUL LAVORO



Innovative powered wheelchair:
Robotic Innovation for Standing and Enabling

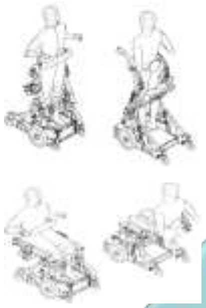
1/1/2013
Start

16/5/2016
Patent application
(priority number:
102016000050120)

31/12/2018
End

Phase V
Clinical validation

Commercialization
(2019/2020)



Phase IV
Technical validation, Certification for electromagnetic compatibility and electrical safety

Phase III:
Rehalization

Phase II:
Design of the device

Phase I:
Analysis of the state of the art

Anthropometric user characteristics	
Weight, min-max, (kg)	52-110
Height, min-max, (cm)	160-200
Device dimensions	
Total lenght (cm)	101
Total width (cm)	70
Total depth (cm)	56
Technical specifications	
Maximum speed (km/h)	5
Turning radius (°)	360
Temperature exercise (min-max) (°C)	-20 - 40
Driving wheel	2x , d = 320 mm
Forward castor wheel	2x , d = 100 mm
Backside castor wheel	2x, d = 120 mm
Electric system	
Lifters motors (W)	4x 55.20
Mobile base motors (W)	2x 350
Batteries	2x 12 V, 40 Ah, LiFePO4

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- Sports biomechanics
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Sports bioengineering and performance biomechanics

Stefano Mazzoleni

Di Paco *et al. Multidisciplinary Respiratory Medicine* 2014, 9:20
http://www.mrmjournal.com/content/9/1/20

Multidisciplinary Respiratory Medicine

ORIGINAL RESEARCH ARTICLE Open Access

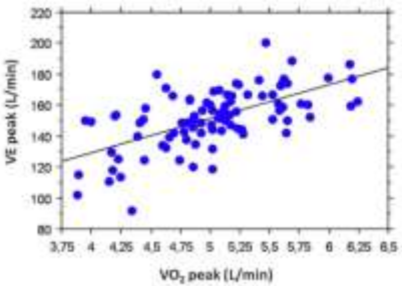
Ventilatory response to exercise of elite soccer players

Adriano Di Paco[1,2*], Giosuè A Catapano[3], Guido Vagheggini[1,2], Stefano Mazzoleni[2,4], Matteo Levi Micheli[5] and Nicolino Ambrosino[1,2]

- N=90 professional soccer players from Italian Major League (serie A)

Procedures:

- **Lung functions test**
- **Electrocardiography**
- **Exercise test**
- **Gas measurement**



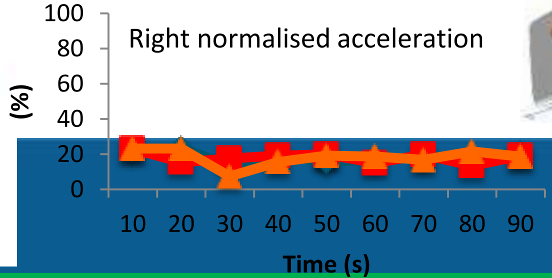
Ricardo Kakà at AC Milan 2003-2009 - *Courtesy of AC Milan*

4 groups based on role:

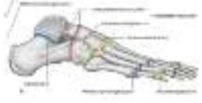
- Forwards (F)
- Central midfielders (CM)
- Central defenders (CD)
- Wide players (WP)

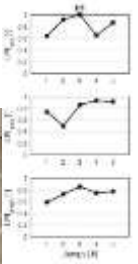
	All	Hi-M n = 45	Lo-M n = 45	p
BMI [Kg/m²]	23.8 ± 1.2	23.6 ± 1.4	24.0 ± 0.9	0.1326
Height [cm]	181.8 ± 5.2	184.0 ± 4.9	182.6 ± 5.2	0.059
Weight [Kg]	79.4 ± 5.5	80.0 ± 5.6	78.8 ± 5.3	0.3221
Age [years]	25.9 ± 4.0	25.2 ± 3.5	26.6 ± 4.4	0.0969
MVV [L/m]	201.1 ± 21.7	206.6 ± 20.4	195.6 ± 21.6	0.0155
FEV_1 [L]	5.0 ± 0.5	5.2 ± 0.5	4.9 ± 0.5	0.0152

Quantitative assessment of professional boxers performances



Ankle injuries prevention in in parachutists (Brigata "Folgore")





Ventilatory response to excercise of elite soccer players

Aim: to evaluate the role of **ventilatory parameters** in maximal exercise performance in **elite soccer players**

Methods

- N=90 professional soccer players from Italian Major League (serie A)
- 4 groups based on role:
  - forwards (F)
  - central midfielders (CM)
  - central defenders (CD)
  - wide players (WP)
- Period: September-December 2009-2012

Procedures:

- **Lung functions test**
- **Electrocardiography**
- **Exercise test**
- **Gas measurement**

Ricardo Kakà at AC Milan 2003-2009 -
Courtesy of AC Milan

- **Lung functions test:** performed by means of pneumotachograph (V-Max Encore, Yorba Linda, CA, USA)
  - *Maximal Voluntary Ventilation (**MVV**) was estimated by multiplying Forced Expiratory Volume at first second (**FEV_1**) value by **40***
- **Electrocardiography (EKG):** performed by means of a 10-electrocardiograph (Cardiosoft, GE medical systems, Fairfield, CT, USA)
  - *Resting and exercise EKG assessed un upright position*
  - *Six precordial leads on the cardiac screening*
  - *Four peripheral leads on the posterior wall of the chest*

$$MEV = v_I + \left(\frac{n}{60}\right)$$

- **Incremental symptom-limited exercise test:** performed on a treadmill (Runrace 900, Technogym, Gambettola, Italy) under EKG and pulse oximetry monitoring. Continuous "ramp" protocol at constant grade (**1%**), starting from **8 km/h**, increasing speed by **1km/h** every **60 seconds**

Test stop: subject's exhaustion.Exercise tolerance was evaluated as the **M**aximal **E**xercise **V**elocity (**MEV**)

	All	Hi-M n = 45	Lo-M n = 45	p
MEV [km/h]	18.5 ± 1.1	19.4 ± 0.6	17.6 ± 0.7	0.0000
$\dot{V}E_{peak}$[L/min]	151.7 ± 19.4	156.2 ± 19.8	147.1 ± 17.9	0.0249
$(V_d/V_t)_{peak}$	0.10 ± 0.03	0.09 ± 0.04	0.11 ± 0.03	0.0548
RR_{peak}[breaths/min]	53.3 ± 4.9	54.5 ± 5.1	52.6 ± 4.6	0.0773
Vt_{peak}[L/min]	2.87 ± 0.45	2.92 ± 0.42	2.84 ± 0.46	0.3848
HR_{peak}[b/min]	186.0 ± 9.5	186.2 ± 9.6	185.7 ± 9.4	0.7911
$\dot{V}O_{2peak}$[mL/min/Kg]	63.3 ± 5.3	63.3 ± 5.3	63.2 ± 5.4	0.9359
BRR[L]	41.9 ± 20.8	42.8 ± 20.1	41.0 ± 21.4	0.6726
BRR%	79.0 ± 9.3	79.1 ± 9.5	78.8 ± 9.1	0.8750

	Hi-VE n = 45	Lo-VE n = 45	p
MEV [km/h]	18.9 ± 0.9	18.1 ± 1.2	0.0008
VE_{peak}[L/min]	166.3 ± 10.4	137.1 ± 14.8	0.0000
$(V_d/V_t)_{peak}$	0.09 ± 0.03	0.10 ± 0.03	0.0741
RR_{peak}[breaths/min]	53.8 ± 5.1	52.7 ± 4.6	0.2617
Vt_{peak}[L/min]	3.11 ± 0.31	2.62 ± 0.34	0.0000
HR_{peak}[b/min]	185.8 ± 8.9	186.1 ± 10.0	0.8946
$\dot{V}O_{2peak}/HR_{peak}$[mL/min/bb]	28.3 ± 4.0	25.4 ± 3.8	0.0004
$\dot{V}O_{2peak}$[mL/min/Kg]	65.7 ± 4.4	60.8 ± 5.3	0.0000
BRR[L]	34.5 ± 18.0	49.3 ± 20.8	0.0006
BRR%	83.4 ± 7.8	74.8 ± 8.7	0.0000
$RR_{peak}[\dot{V}CO_2/\dot{V}O_2]$	1.08 ± 0.17	1.10 ± 0.10	0.4576
MVV[L/min]	208.0 ± 18.0	194.2 ± 22.9	0.0028
FEV_1[L]	5.2 ± 0.4	4.8 ± 0.6	0.0021

Results

MEV median = 18.65 km/h

VE_{peak} median = 153.06 L/min

$VE_{peak}=41.76+(21.88*VO_{2peak})$ r=0.619; p<0.001

	All	Hi-M n = 45	Lo-M n = 45	p
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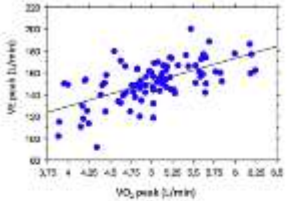
MVV [L/m]	201.1 ± 21.7	206.6 ± 20.4	195.6 ± 21.6	0.0155
FEV_1 [L]	5.0 ± 0.5	5.2 ± 0.5	4.9 ± 0.5	0.0152

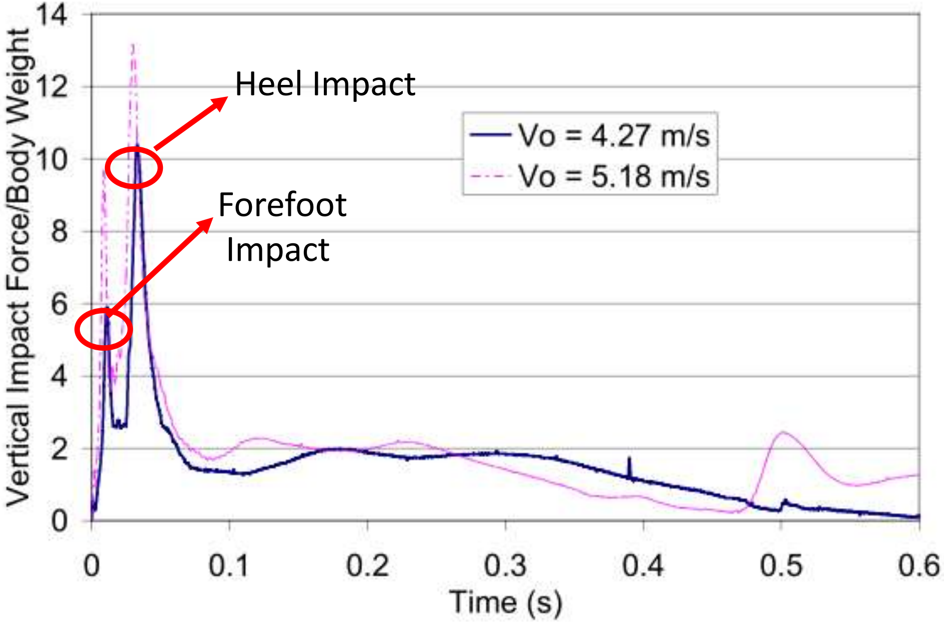


Di Paco, et al. Ventilatory response to excercise of elite soccer players. Multidiscip Respir Med. 2014; 9(1): 20. Published online 2014

Ankle injuries prevention in in parachutists (Brigata Paracadusti “Folgore”)

Ground Force Reaction during a

Vo = 4.27 m/s	Time to 1st Peak	0.033
	1st Peak	6.45
	Time to 2nd Peak	0.053
	2nd Peak	9.34
Vo = 5.18 m/s	Time to 1st Peak	0.031
	1st Peak	11.31
	Time to 2nd Peak	0.048
	2nd Peak	14.07



PLF tests were conducted **indoor**. The experimental setup involved collection of ground reaction forces, lower extremity kinematics data using a **force platform system.**

Sacco et al., Rev Bras Med Esporte 2004

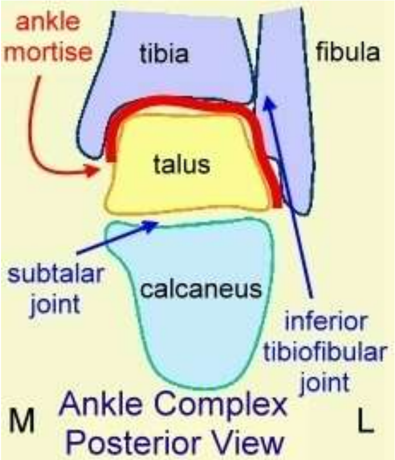
Foot and Ankle Anatomy

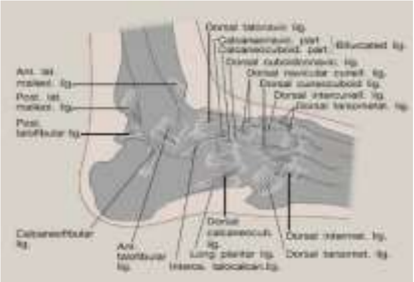
It is made up of:

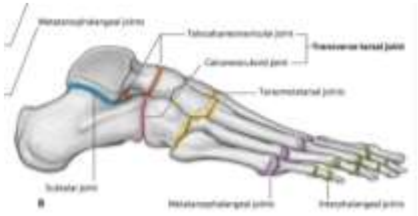
- 28 bones (26 for the foot and 2 for the leg (Fibula and Tibia))
- 33 ligaments
- 12 muscles

and 4 joints:

- Subtalar (Talocalcaneal)
- Tibiotalar (Talocrural, ankle mortise)
- Tibiofibular (Inferior)
- Tranverse-Tarsal (Talocalcaneonavicular)







Brockett et al., ScienceDirect 2016

Biomechanics of the foot

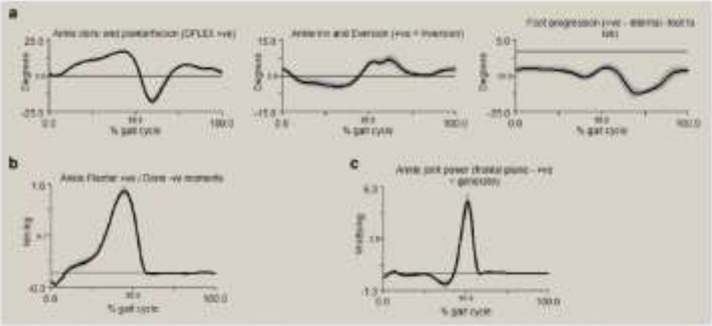


Figure 6 Diagram illustrating typical outputs from gait analysis of five walking trials. a) representing ankle complex rotation in sagittal, frontal and transverse planes (left to right, respectively); b) sagittal plane ankle moments and c) sagittal plane ankle power. The shaded area on all graphs represents ±1 standard deviation. Figure adapted from Visual 3D (C-Motion, Rockville, Maryland).

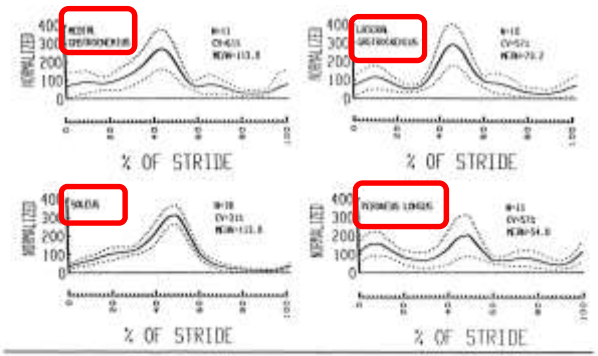
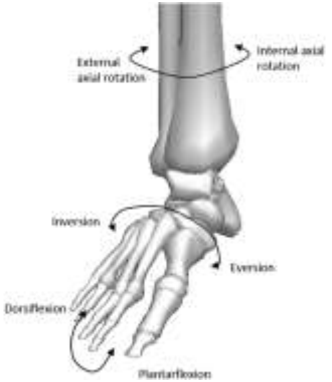
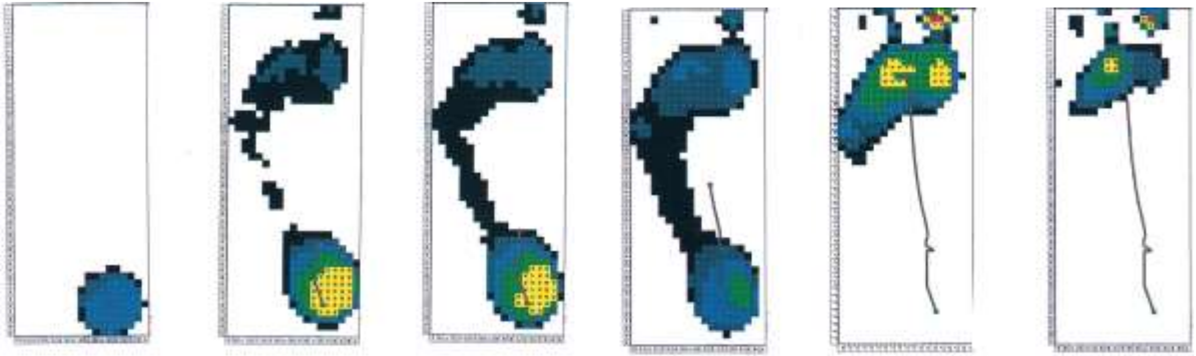
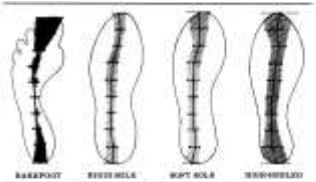


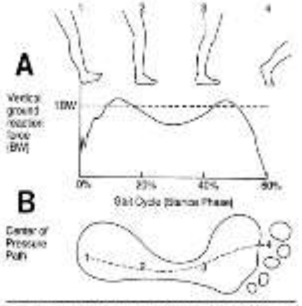
Fig. 2. Electromyographic activity (normalized to each subject's mean EMG) for six muscles during walking. Plots show mean EMG (solid line) and one standard deviation (dotted lines) for samples of varying size. Activity of medial and lateral gastrocnemius muscles is very similar and is combined for discussion in text. (Reprinted with permission.)



Sequence of pressure plots over the entire stance phase of walking





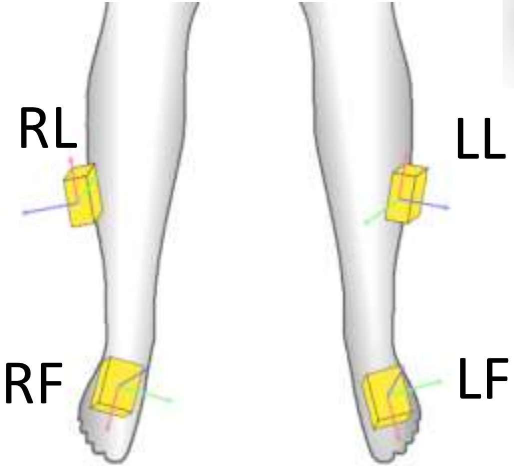


Equipment

4 IMU sensors

RL = right leg
LL = left leg
RF = right foot
LF = left foot

shimmer

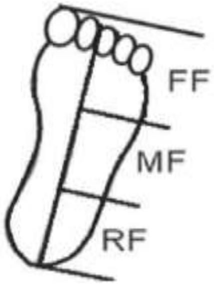


1 insole with FSR sensors

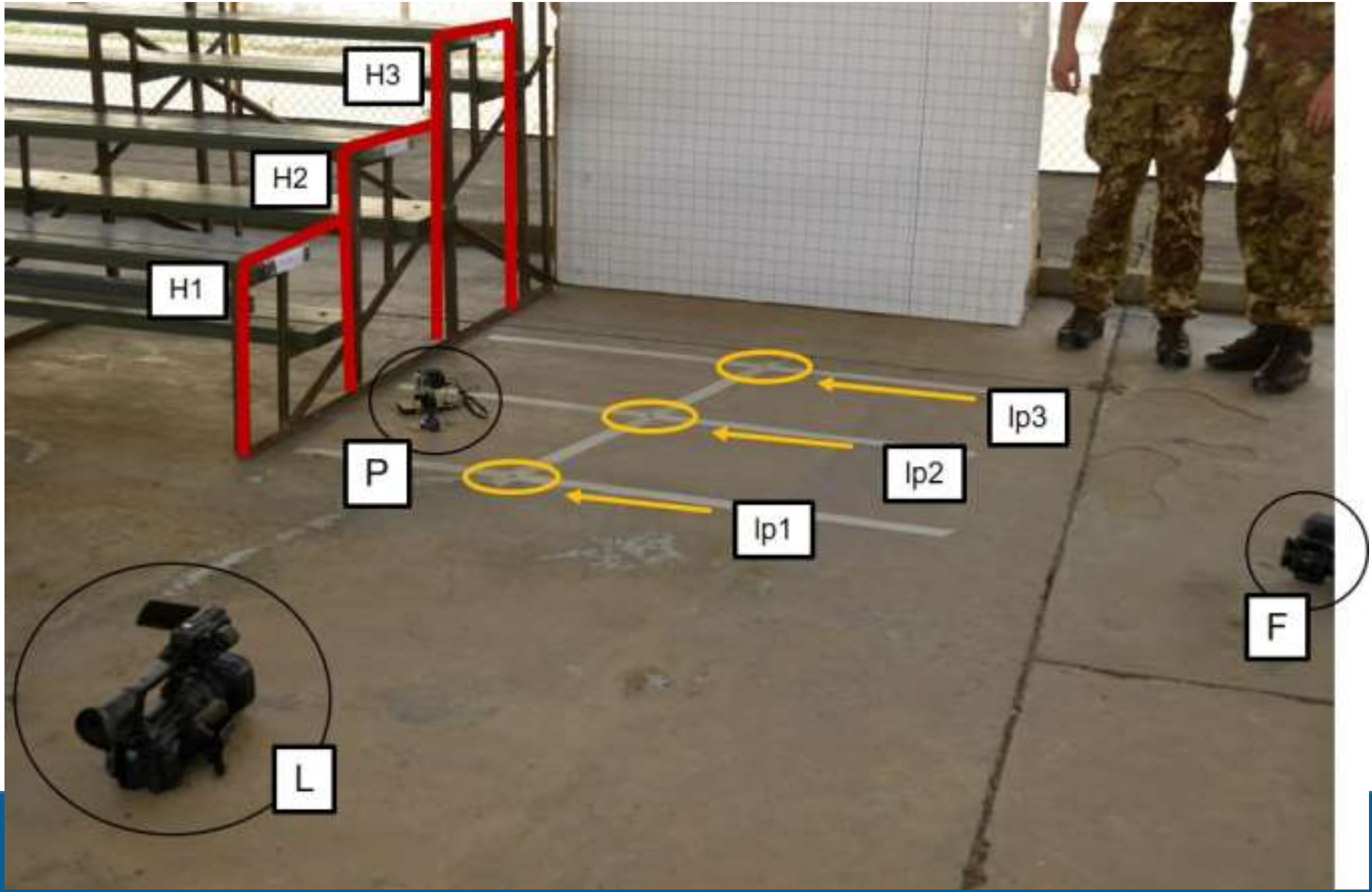
FF = forefoot
MF = midfoot
RF = rearfoot

Tekscan

F-Scan® In-Shoe Analysis System



3 videocameras



H1 = 0,51 m

H2 = 0,71 m

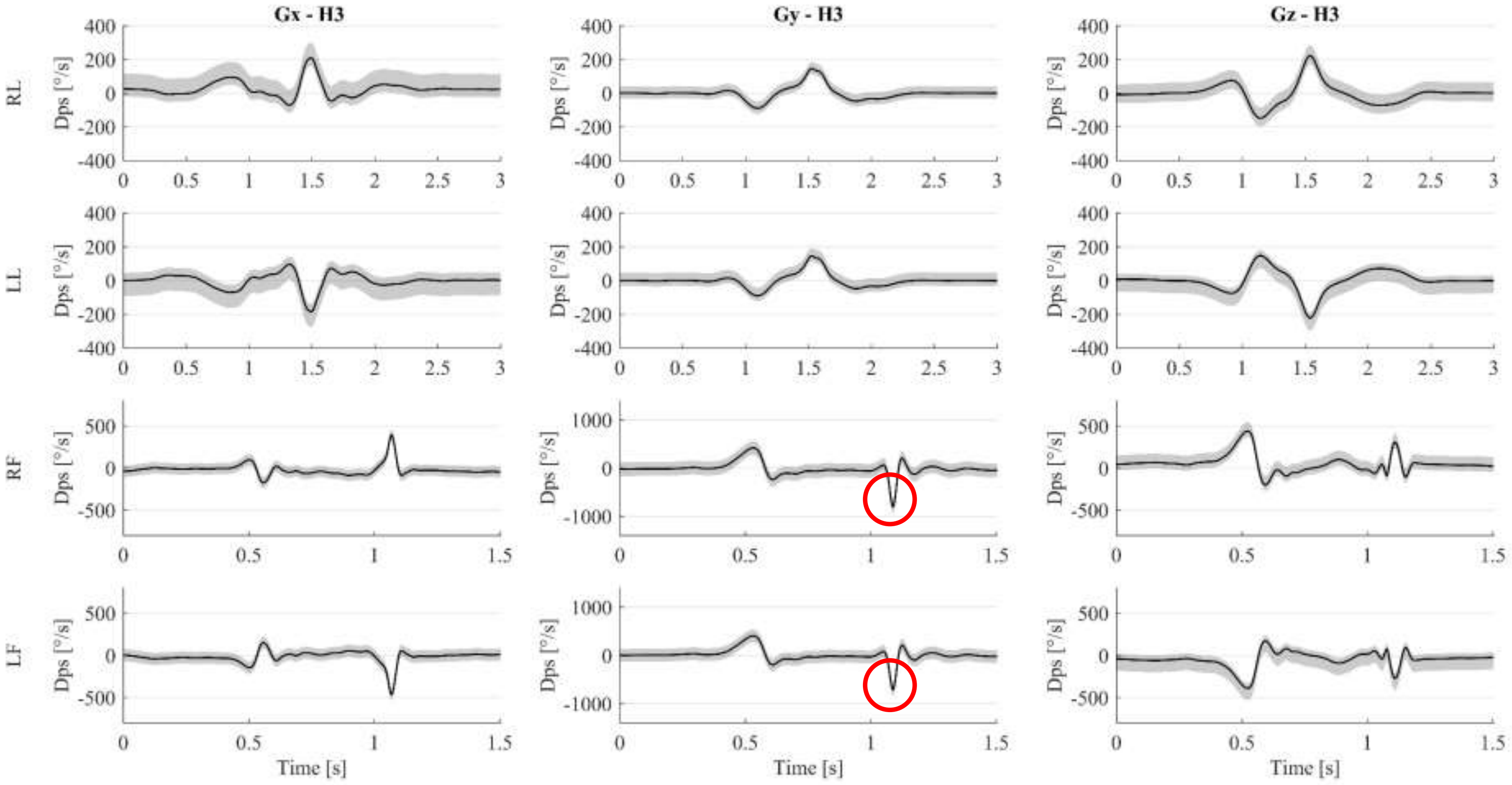
H3 = 1,04 m

lp = landing point

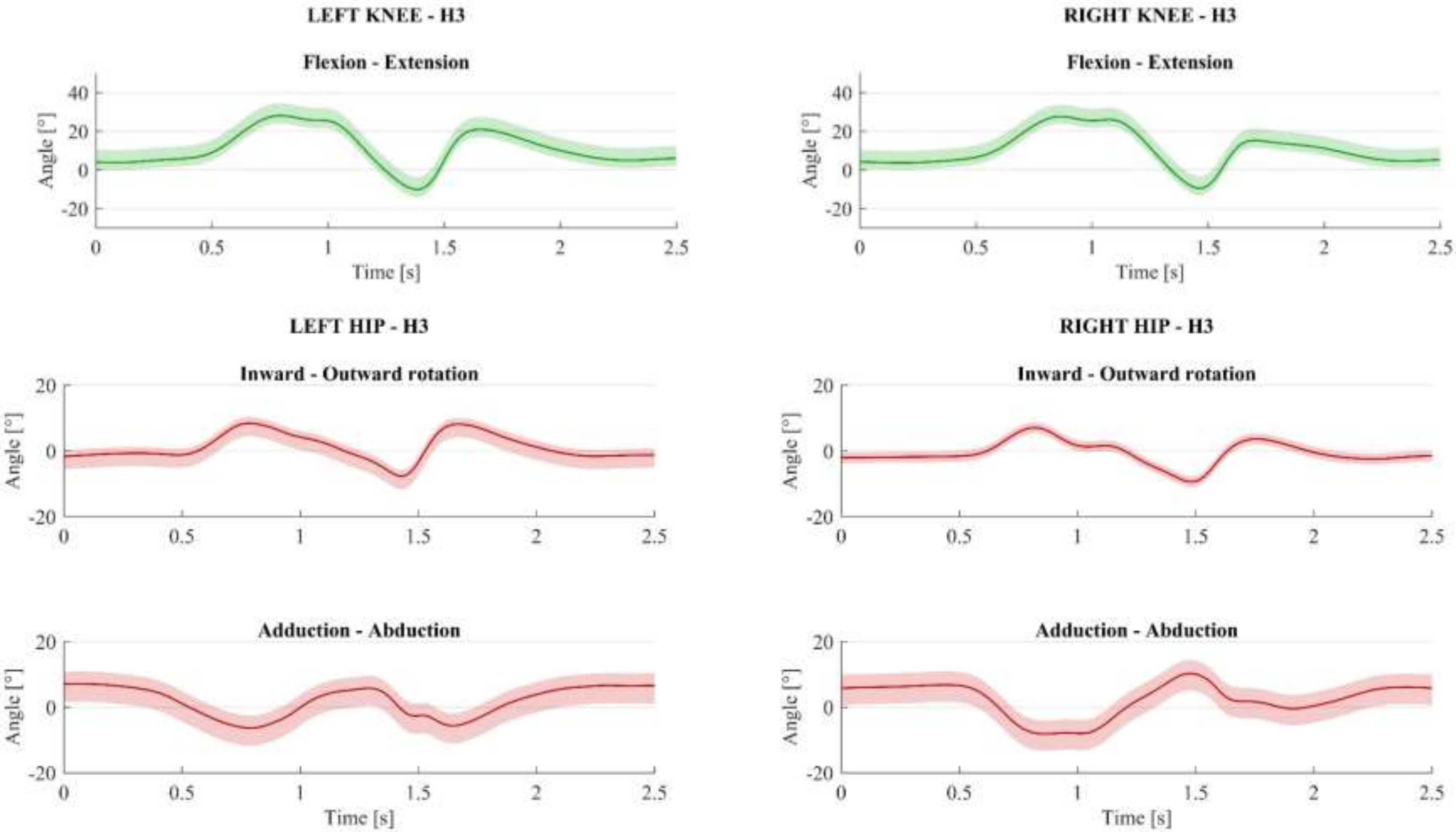
F = Frontal view
L = Lateral view
P = Posterior view

Jump dynamics analysis

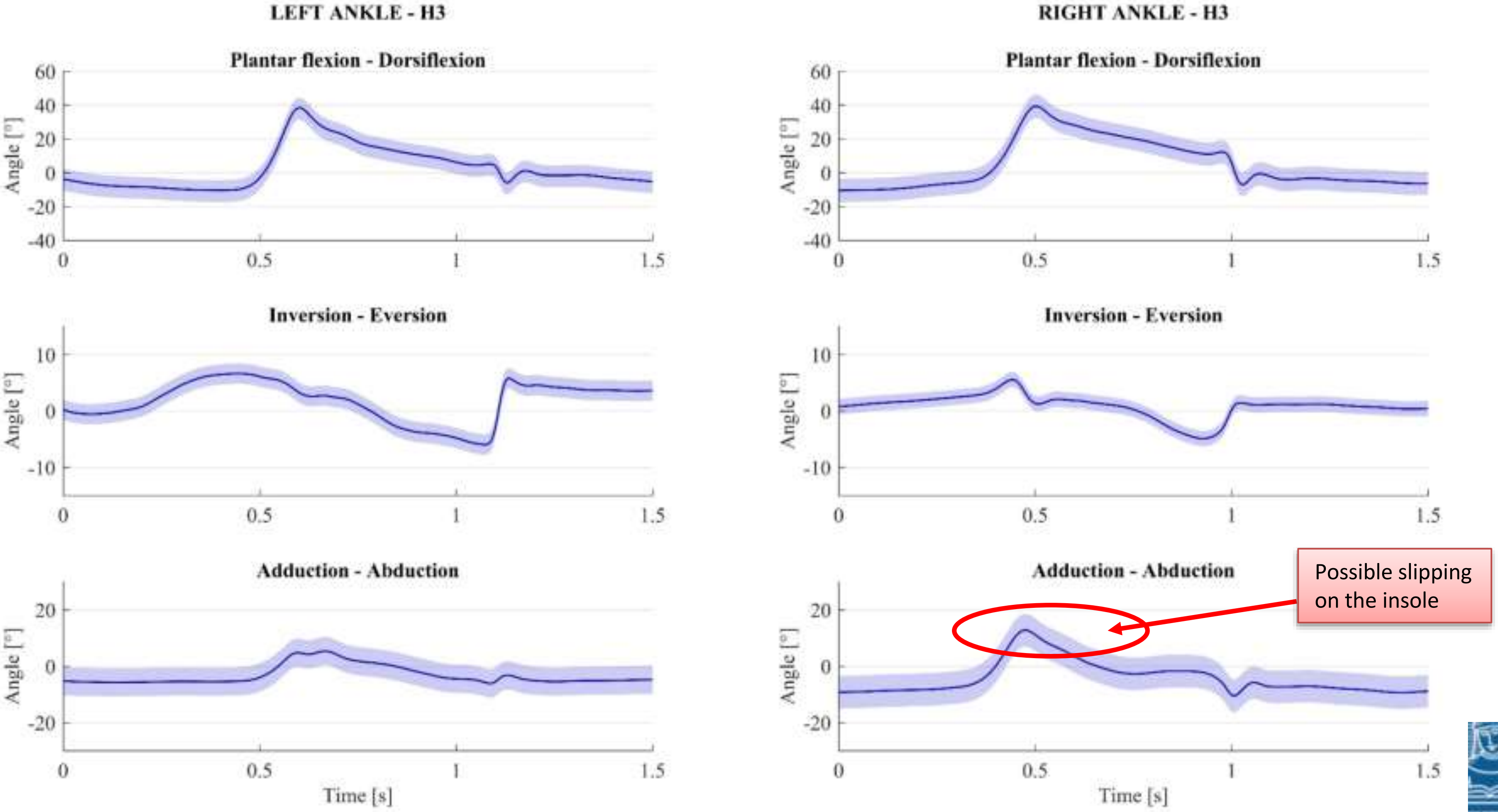
Angular speed (Dps = °/s) XYZ – H3



Range of motion– H3



Range of motion– H3



Landing Performance Index(LPI):

Single jump (sj):

$$LPIsj_{vel} = \frac{v_i}{\bar{v}}$$

$$LPIsj_{dps} = \frac{X_i}{\bar{X}} + \frac{Y_i}{\bar{Y}} + \frac{Z_i}{\bar{Z}}$$

$$LPIsj_{BWR} = \frac{BWR_{i_{(fore)}}}{\overline{BWR}_{(fore)}} + \frac{BWR_{i_{(mid)}}}{\overline{BWR}_{(mid)}} + \frac{BWR_{i_{(rear)}}}{\overline{BWR}_{(rear)}}$$

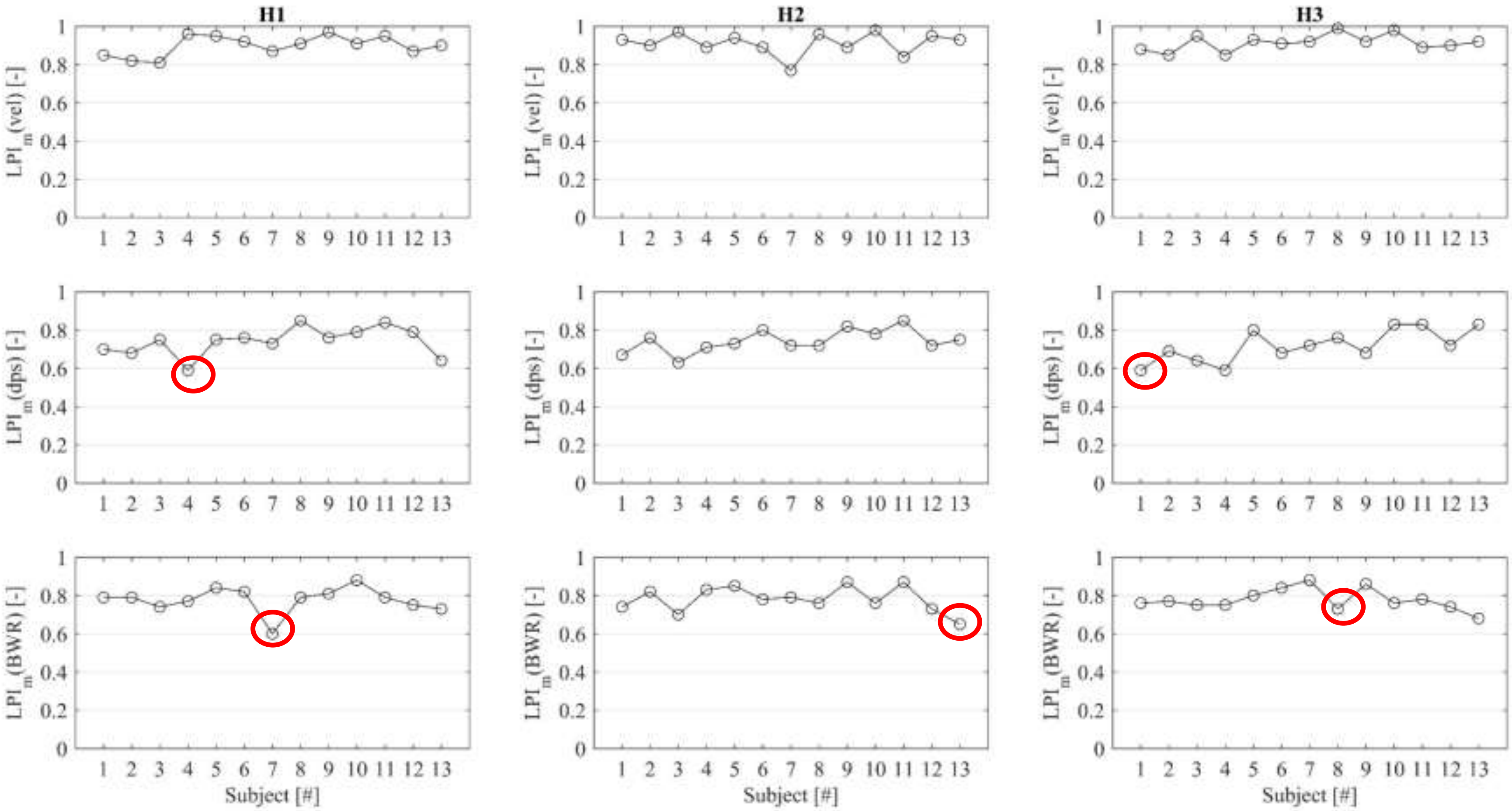
Mean of jumps (m):

$$LPIm_{vel} = \frac{\bar{v}}{v_{max}}$$

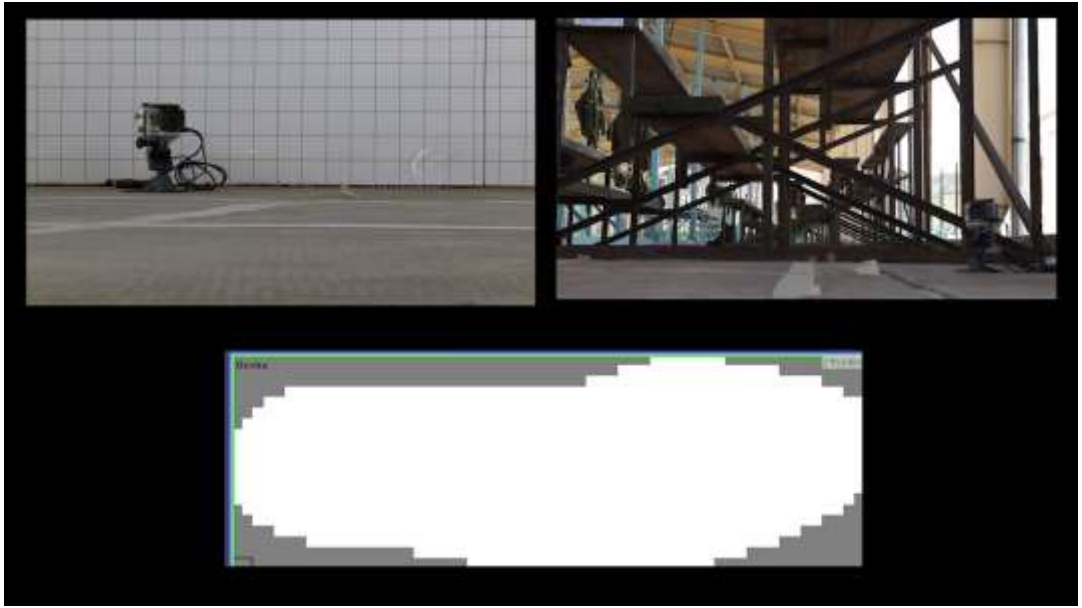
$$LPIm_{dps} = \frac{\bar{X}}{X_{max}} + \frac{\bar{Y}}{Y_{max}} + \frac{\bar{Z}}{Z_{max}}$$

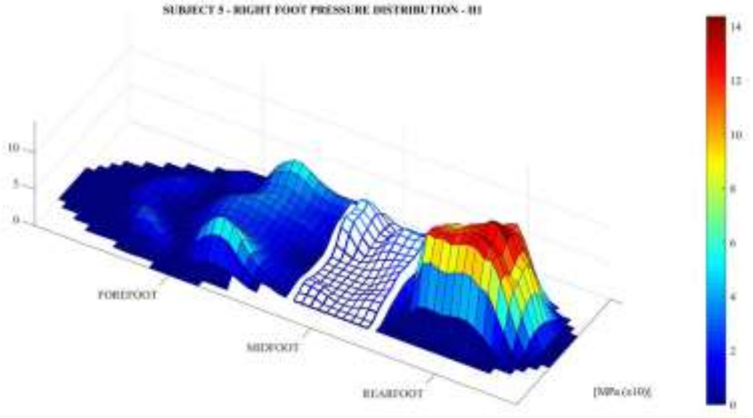
$$LPIm_{BWR} = \frac{\overline{BWR}_{(fore)}}{BWR_{max_{(fore)}}} + \frac{\overline{BWR}_{(mid)}}{BWR_{max_{(mid)}}} + \frac{\overline{BWR}_{(rear)}}{BWR_{max_{(rear)}}}$$

LPIm

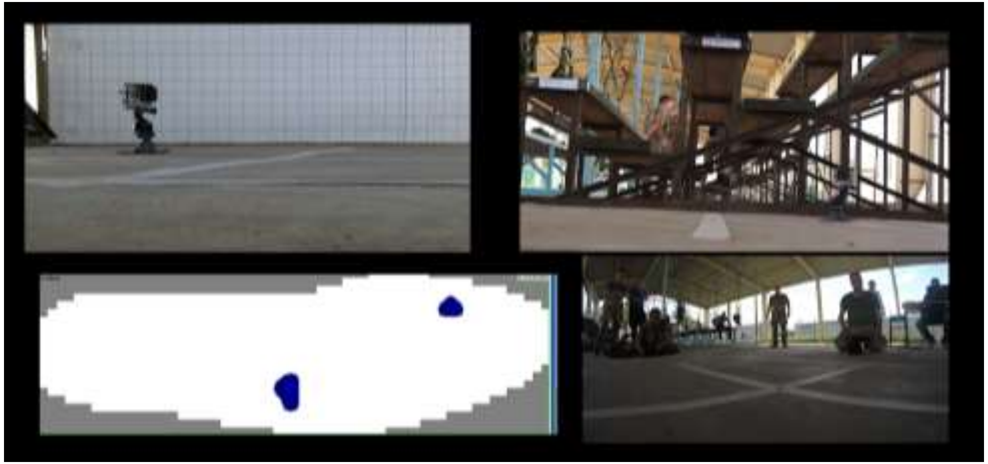


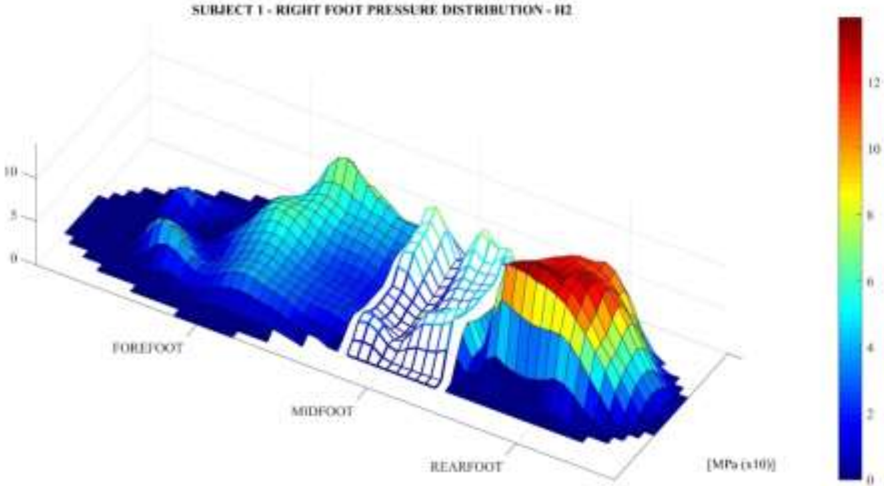
Subject #5(20 years – 84 kg – 173 cm) correct jump– H3



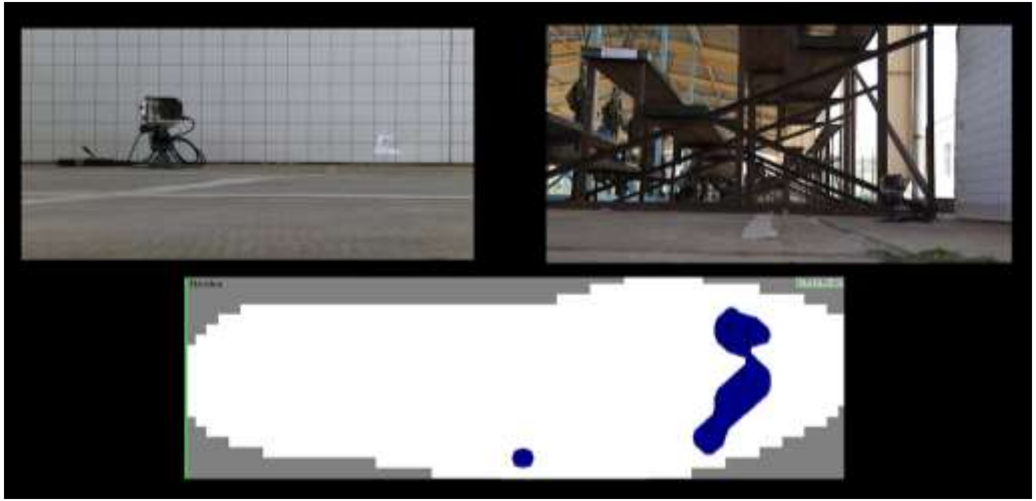


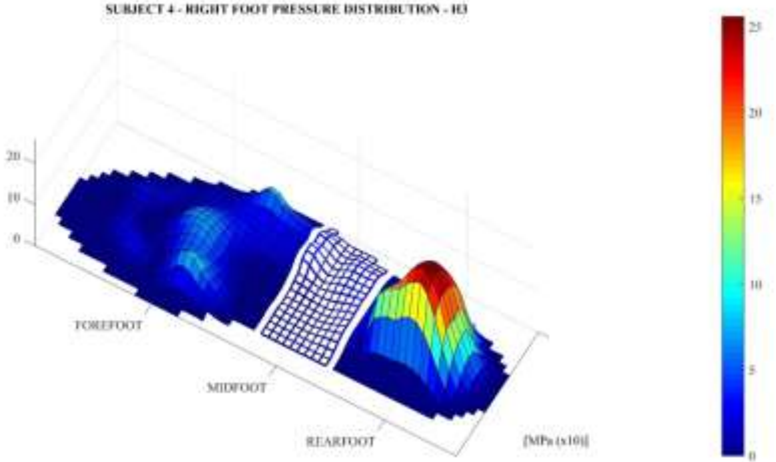
Subject # 1 (26 years – 100 kg – 176 cm), 1) Flat landing– H2



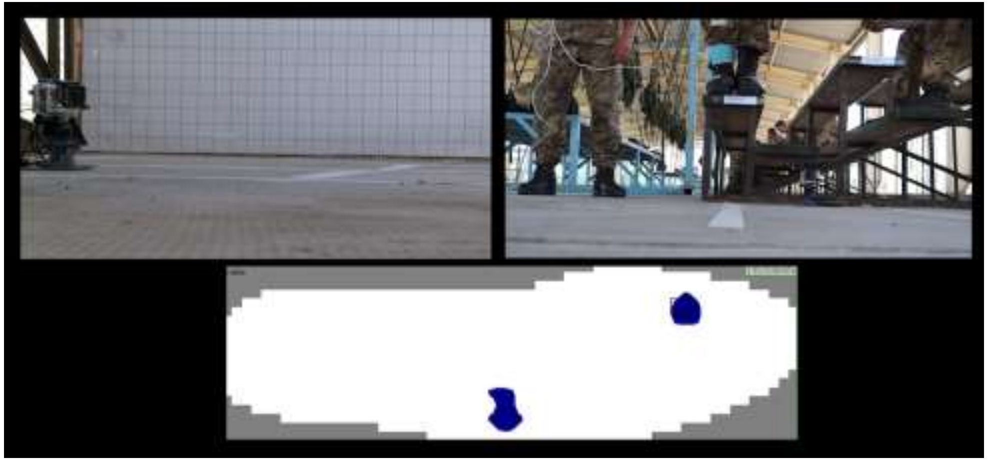


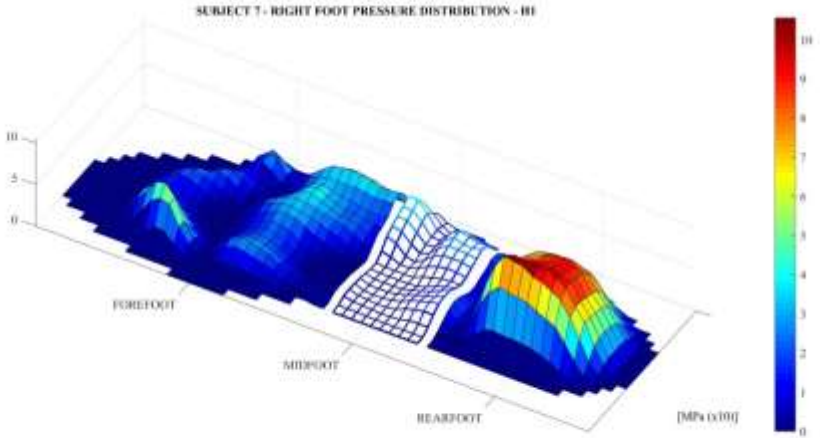
Subject # 4 (20 years– 72 kg – 175 cm), 2) Squat landing– H3



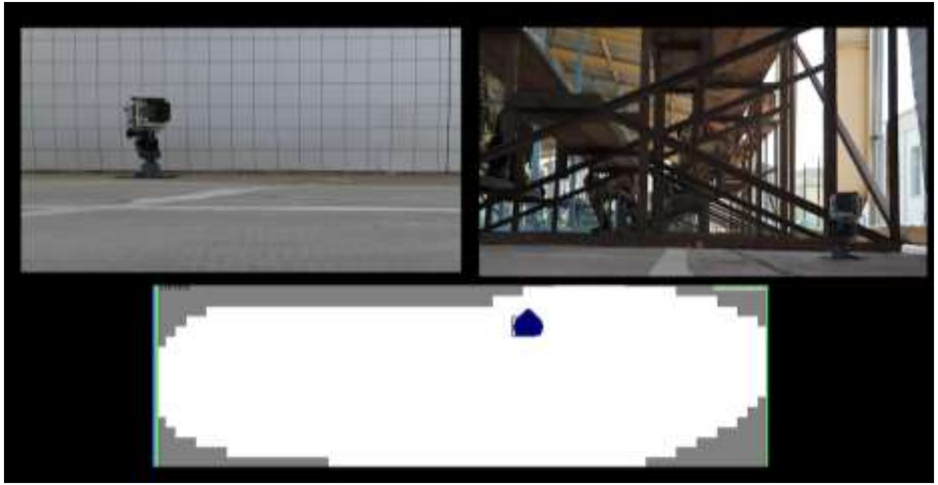


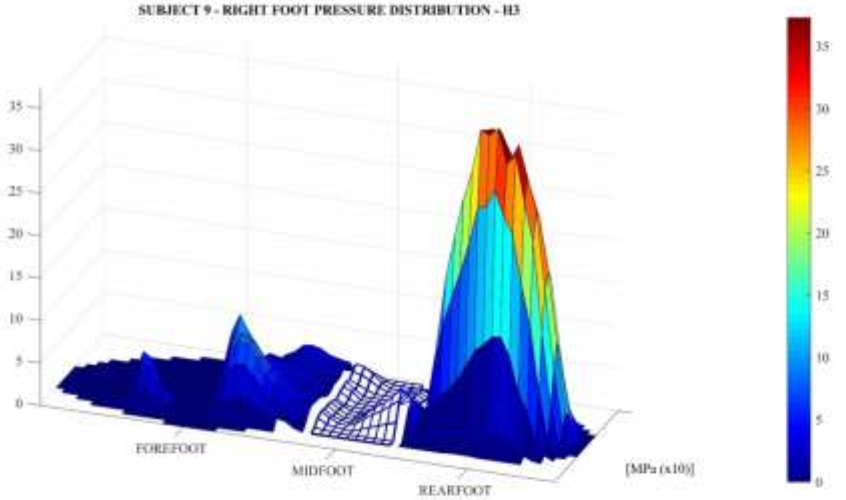
Subject # 7 (19 years– 75 kg – 173 cm), 3) Forward step landing– H1





Subject # 9 (24 years– 74 kg – 175 cm), 4) Push upward landing– H3





Sports bioengineering and performance biomechanics

Salvatore Cimmino, 54 yrs
Ponza-Ventotene 27 miles - 17 hrs swimming
Start: 11:00 pm Sept 18 2018, arrival: 3:00 pm Sept 19 2018

Ongoing research projects and collaborations

Stefano Mazzoleni

(2018-2020) **VERSUS - Virtual-Reality Enhanced Rehabilitation for Sustainable and Usable Services**, funded by Regione Toscana, within the framework POR-FESR 2014-2020, Bando n.2: progetti strategici di ricerca e sviluppo delle MPMI (budget: 211.229,00 €) - *Ranked 1st among 220+ research proposals in MEDTECH domain*

(2018-2020) **ARCONTE - Piattaforma multidisciplinare web-based integrata per la gestione delle procedure perioperatorie e delle pratiche medico chirurgiche**, funded by Regione Toscana, within the framework POR-FESR 2014-2020, Bando n.2: progetti strategici di ricerca e sviluppo delle MPMI (budget: 200.000,00 €)

(2018-2020) **ARONA - Navigazione Chirurgica Assistita da Robotica Avanzata**, coordinator: MASMEC SpA (Modugno, Bari, Italy), funded by Italian Ministry of Education, University and Research (MIUR) wirthin the framework of National Research Program (PNR) 2015 – 2020 (budget: 350.000,00 €), Partners: Università Campus Biomedico, Istituto Tumori Bari, ASL Toscana Nord-Ovest, The BioRobotics Institute

(2017-2019) **ROBOVIR - Sviluppo e validazione di una piattaforma robotica per la riabilitazione motoria e il coordinamento visuomotorio degli arti superiori con scenari di realtà virtuale relativi ad attività di vita quotidiana,** funded by INAIL (Italian Workers Compensation Authority) (budget: 226.000,00 €), PI: Stefano Mazzoleni, Partners: Istituto Superiore Sanità, Politecnico di Bari, ASL Toscana Nord-Ovest

(2014-2018) **RF-2011-02346770 Clinical and healthcare strategies for improving quality of life in persons affected by spinal cord injuries: Tuscany regional network and use of innovative technological devices**, funded by Italian Ministry of Health (budget 108.176,32 €), PI: Dr. Giulia Stampacchia (Pisa University Hospital), Partners: Spinal Cord Injury Unit, Firenze University Hospital, The BioRobotics Institute

ROBOVIR - Sviluppo e validazione di una piattaforma robotica per la riabilitazione motoria e il coordinamento visuomotorio degli arti superiori con scenari di realtà virtuale relativi ad attività di vita quotidiana

ROBOVIR

Start: 29/06/2017

Duration: 30 months

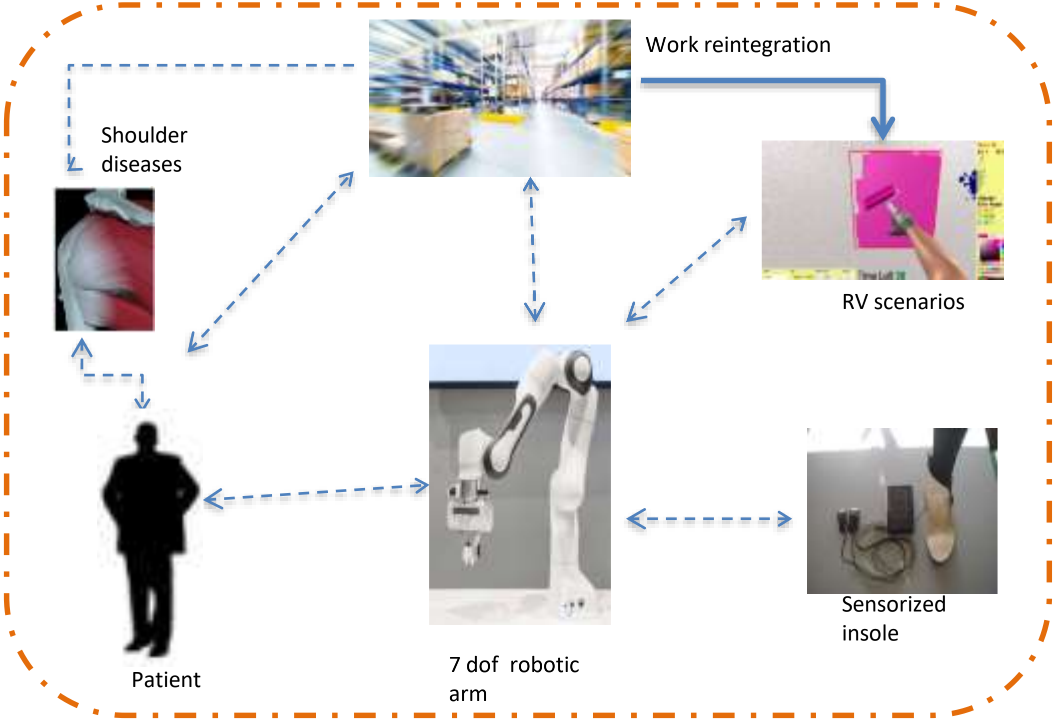
End: 29/12/2019

Coordinator:
The BioRobotics Institute, Scuola Superiore Sant'Anna

Partner:
Istituto Superiore di Sanità
Poltiecnico di Bari
Azienda USL Toscana Nord Ovest

The project is **funded** by **INAIL**:

- Budget TOT di Partenariato: 384.000,00€
- Contributo concesso al partenariato: 226.000,00€



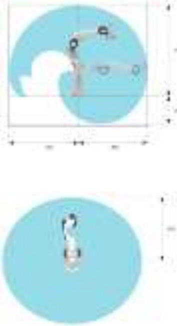
ROBOVIR - Sviluppo e validazione di una piattaforma robotica per la riabilitazione motoria e il coordinamento visuomotorio degli arti superiori con scenari di realtà virtuale relativi ad attività di vita quotidiana

Methods

The robotic platform consists of:

- **end-effector characterized by 7 DoFs**

- **different sensors** to analyse:
    - upper limb biomechanics
    - visuomotor coordination
    - role of tactile sensory



Robot Panda (Franka Emika)

Control	
interfaces	• Ethernet (TCP/IP) for Internet and/or shop-floor connection • power connector IEC 60320-C14 (V-Lock) • Arm connector
controller size (19")	355 x 483 x 89 mm (D x W x H)
supply voltage	100 VAC - 240 VAC
mains frequency	47-63 Hz
power consumption	• max. 600 W • average ~ 300 W
active power factor correction (PFC)	yes
weight	~ 7 kg
protection rating	IP20
ambient temperature	• +15°C to 25°C (typical) • +5°C to + 45°C (extended) [3]
air humidity	20% to 80% non-condensing

Versatile & programming control

Arm	
degrees of freedom	7 DOF
payload	3 kg
sensitivity	torque sensors in all 7 axes
maximum reach	855 mm
joint position limits [°]	A1: -166/166, A2: -101/101, A3: -166/166, A4: -176/-4, A5: -166/166, A6: -1/215, A7: -166/166
joint velocity limits [°/s]	A1: 150, A2: 150, A3: 150, A4: 150, A5: 180, A6: 180, A7: 180
Cartesian velocity limits	Up to 2 m/s end effector speed
repeatability	+/- 0.1 mm (ISO 9283)
interfaces	• Ethernet (TCP/IP) for visual intuitive programming with Desk • input for external enabling device • input for external activation device or a safeguard • Control connector • Hand connector
interaction	enabling and guiding button, selection of guiding mode, Pilot user interface
mounting flange	DIN ISO 9409-1-A50
installation position	upright
weight	~ 18 kg
protection rating	IP30
ambient temperature	• +15°C to 25°C (typical) • +5°C to + 45°C (extended) [3]
air humidity	20% to 80% non-condensing

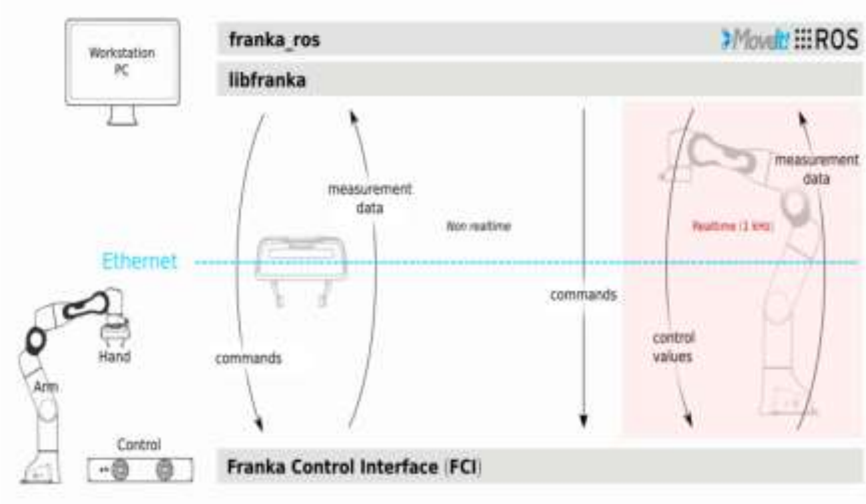
The robotic platform will be integrated with:

- **virtual reality (VR) rehabilitation scenarios** including **ADLs**
- **adaptive control system**

https://www.franka.de/panda

ROBOVIR - Sviluppo e validazione di una piattaforma robotica per la riabilitazione motoria e il coordinamento visuomotorio degli arti superiori con scenari di realtà virtuale relativi ad attività di vita quotidiana

Technical validation in progress



ARCONTE - Piattaforma multidisciplinare web-based integrata per la gestione delle procedure perioperatorie e delle pratiche medico chirurgiche

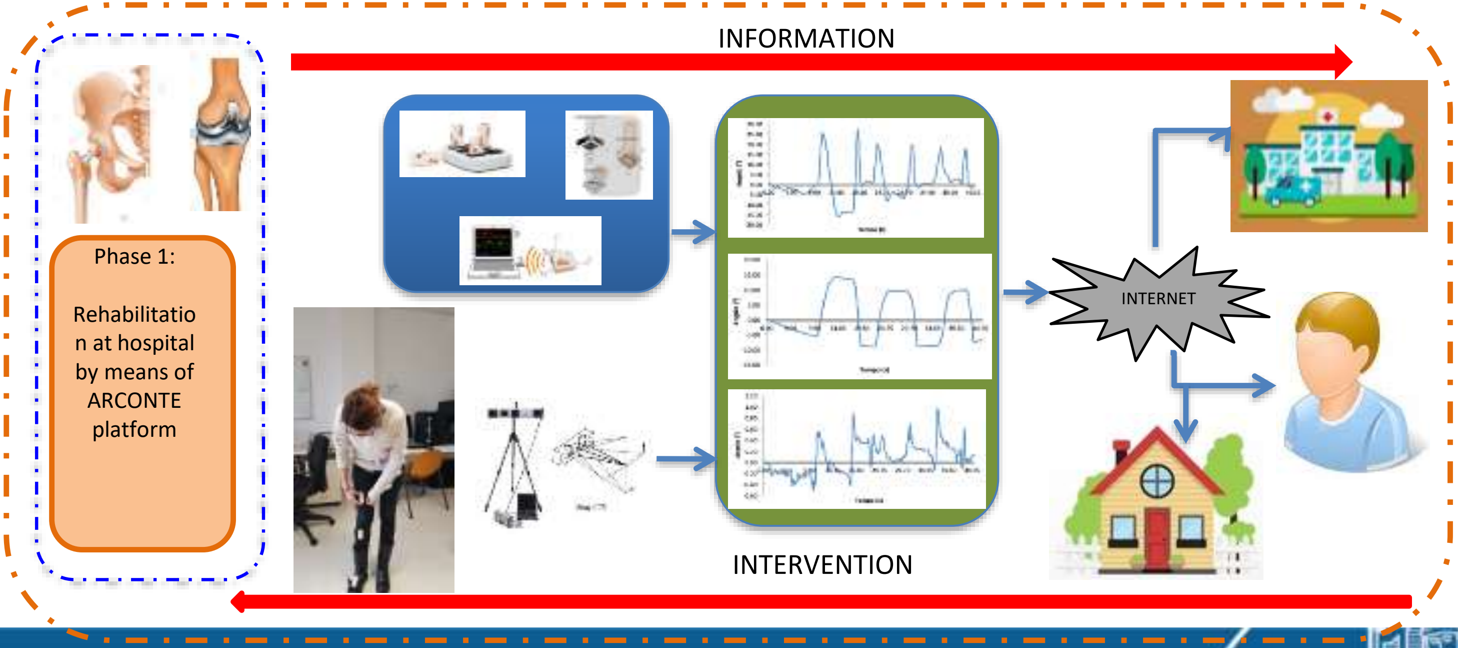
Start: 15/03/2018

Duration: 18 months

End: 14/09/2019

Coordinator:
R.C.J. Soft S.r.l.
Partner:
MEHRIT S.r.l.
The BioRobotics Institute, Scuola Superiore Sant'Anna
Università degli Studi di Firenze
VICS S.r.l.

The project is **funded** by **Regione Toscana**:
Total budget: 1.209.048,74€
Funding: 604.524,38€



VERSUS - Virtual-Reality Enhanced Rehabilitation for Sustainable and Usable Services

VERSUS

Start: 02/10/2017 → End: 14/09/2019

Duration: 23 months

Coordinator:
SIGNO MOTUS S.r.l.
Partner:
VRMEDIA S.r.l.
MOV'IT S.r.l.
HORENTEK S.r.l.
DIELECTRIK S.r.l.
The BioRobotics Institute, Scuola Superiore Sant'Anna
BTR
CPA WEB SOLUTIONS

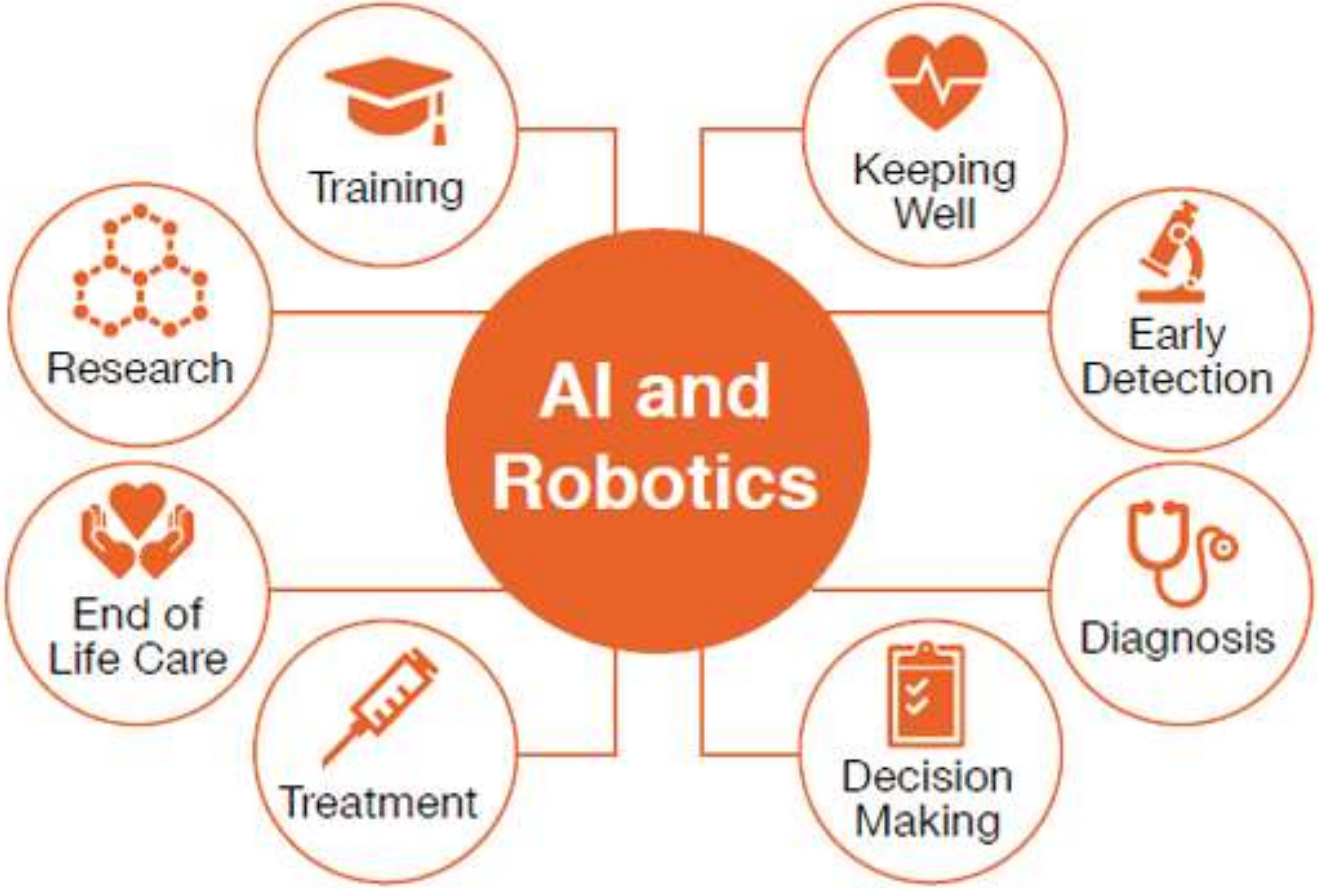
The project is **funded** by **Regione Toscana**:
Budget TOT di Partenariato: 1.786.282,00€
Contributo concesso al partenariato: 893.141,00€

At hospital rehabilitation: subacute phase

At hospital rehabilitation: chronic phase

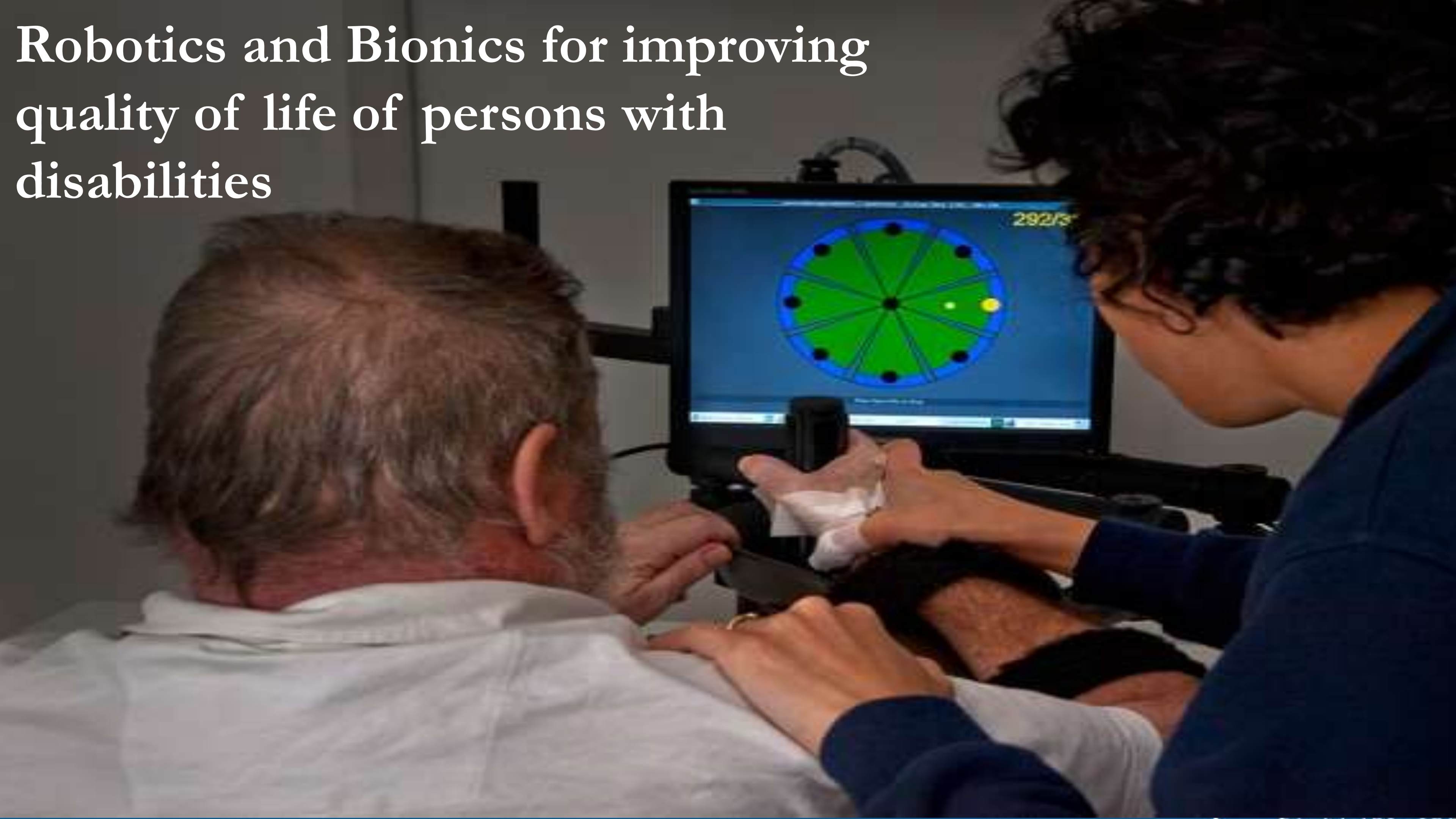
Outline of the presentation

- BioRobotics and Bionics convergence
- Rehabilitation and Assistive Robotics
  - Upper limb robot-assisted therapy
  - Gait robot-assisted therapy
  - Precision orthopaedic surgery - Precision orthopaedic rehab
  - RISE robotic wheelchair
- Sports biomechanics
- Lessons, new scenarios and challenges

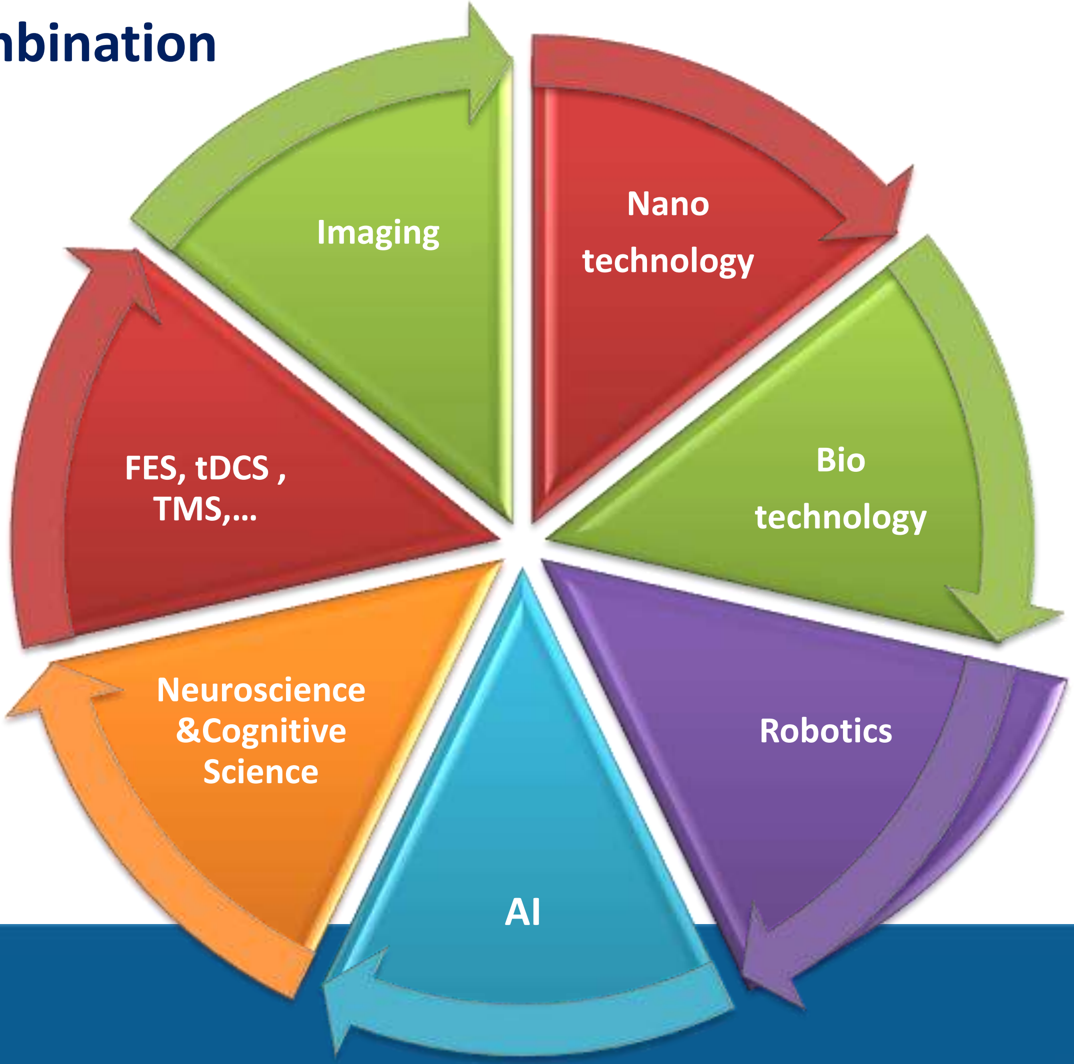


Source: https://www.pwc.com/gx/en/industries/healthcare/publications/ai-robotics-new-health/transforming-healthcare.html

Robotics and Bionics for improving quality of life of persons with disabilities



Integration and combination of technologies for improving functional outcome



Ethical issues and challenges

- A **new alliance** among researchers, stakeholders and institutions is needed to **govern** social, economic, cultural and anthropological changes associated to scientific and technological innovations in the field of biomedical applications (including micro- and nanosystems):
  - Personalised medicine
  - Regenerative medicine
  - Biomaterials
  - Nanomedicine
  - Gene editing
- Relevant **ethical issues** in biomedical technology:
  - Protecting human subjects in clinical trials
  - Affordability
  - Privacy and protection of personal data
  - Stem cells research
  - Bioterrorism

Open issues

- **Personalised rehabilitation** (duration, intensity, patient-robot interaction) and **assistance**
- **Precision rehabilitation** (kinematic/biomechanical metrics)
- **Integration among different technologies** (robotics, tDCS, FES,…)
- **Continuity of care** (from hospitalisation to home-based programmes) and **patient empowerment**
- **Combined design approach** (clinical and engineering): motions and emotions
- **Need of patients stratification** (severity, lesion site and volume, gender, age,…)
- **Education in PM&R** (Master programmes, PhD programmes, specialisation schools, master, professional education courses,…)
- **Privacy and protection of personal data** (data transmission)

Some conclusions…

- Technologies for rehabilitation, assistance and sports biomechanics (robots, wearable sensors): **movement quantitative and qualitative assessment** (kinematics, EMG, forces/pressures – upper limb/gait/posture)
- **Wearable sensors** as safe, valid and reliable tool for **non invasive functional assessment** of movements and activities of daily living
- Implementation of **viable healthcare services/solutions** (organisational, economic, clinical)
- **Integrated technologies for e-health services:** to cure by increasing appropriateness and patients safety, but even accessibility, equity and diagnosis/cure procedures speed

Bioengineering Rehabilitation Laboratory

The BioRobotics Institute, Scuola Superiore Sant'Anna

Stefano Mazzoleni, PhD, Assistant Professor

Vi Do Tran, PhD in Biorobotics

Elena Battini, Research Assistant

Thanks for your attention!

The BioRobotics Institute
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Tel. + 39 050 883132 - Fax + 39 050 883101