香港中文大學
The Chinese University of Hong Kong

Exoskeleton Robotics: Design for Stroke Rehab
用于中風康復的外骨骼机器人

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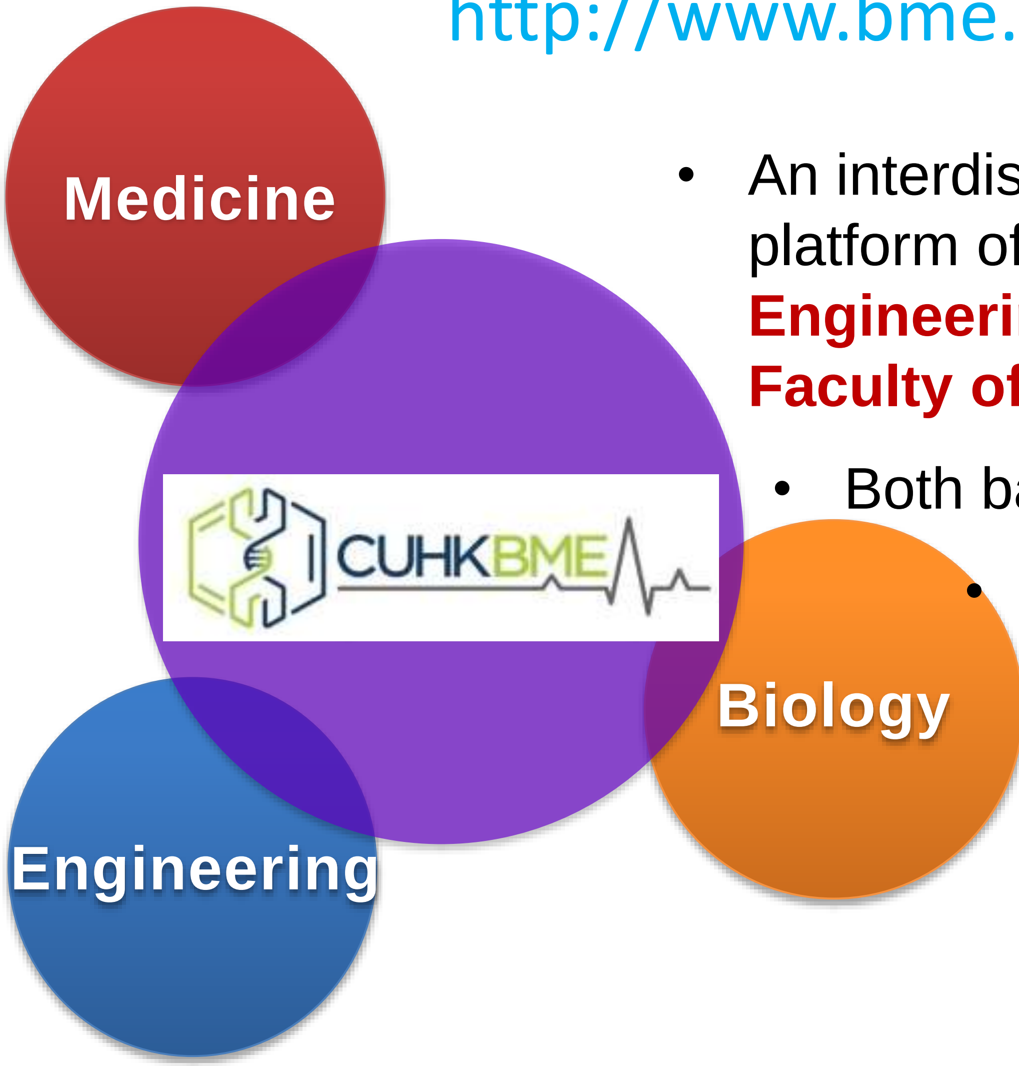
CUHKBME

Biomedical Engineering (BME)

http://www.bme.cuhk.edu.hk



- An interdisciplinary research and education platform offered by the **Faculty of Engineering** in close collaboration with the **Faculty of Medicine**
  - Both basic and applied research
    - Wide access to courses offered by different divisions
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CUHK BME

Welcome to CUHK, Faculty of Engineering

CUHK BME

- Explore, Innovate and Care
  探索 創新 關懷
- To become a cradle for world-class leaders in BME through education and research
- CUHK has recently launched four major research initiatives related to BME:
  1.The Institute of Tissue Engineering and Regenerative Medicine (iTERM) Link
  2.The Chow Yuk Ho Technology Centre for Innovative Medicine (TIM) Link
  3.The CUHK T Stone Robotics Institute (CURI) Link
  4.The Gerald Choa Neuroscience Centre (GCNC) Link

BME professors, associate members and collaborators in 2017

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Acknowledgements

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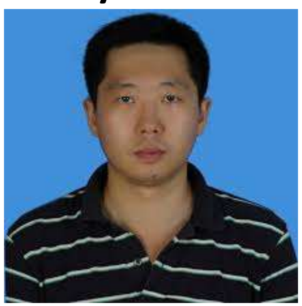

Professor Song Rong
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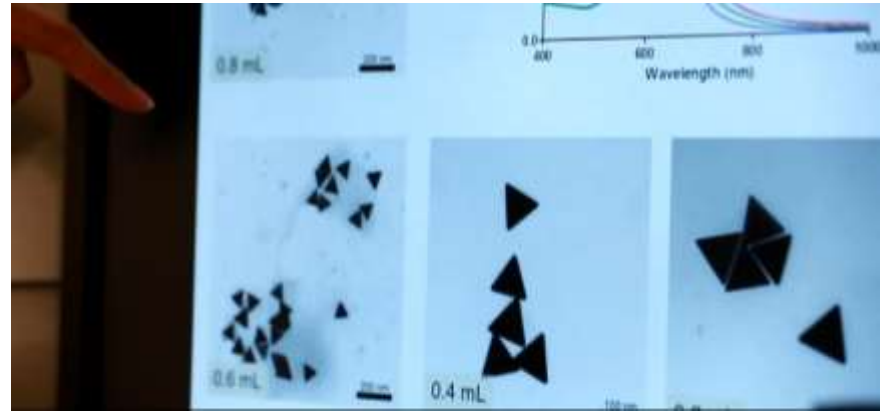
李乐 - 中山大学附属
第一医院

Research TEAMS

Fields of Specialization in BME

Biomaterials and Regenerative Medicine



Biomolecular Engineering and Nanomedicine

Medical Imaging and Informatics

Medical Instrumentation and Biosensors

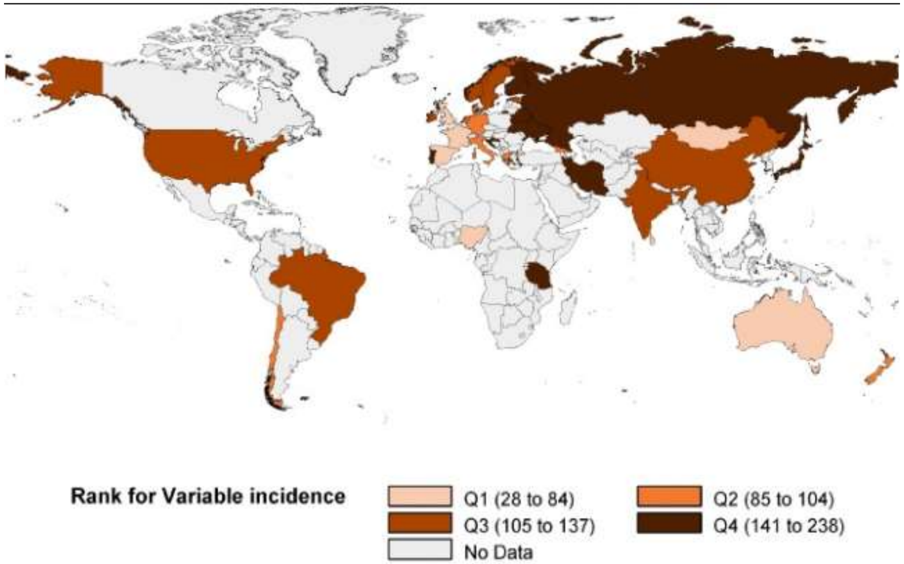
How to make a survivor smile?

How Hong Kong Smart Robot Leg can facilitate the brain to relearn how to walking again ?

Stroke Rehabilitation Market

- Stroke is the **Leading Disability** in the world, among the U.S, Europe and Asia
- **Golden Period** **(within 3 months after stroke)** for better motor recovery is in Early Stroke Period

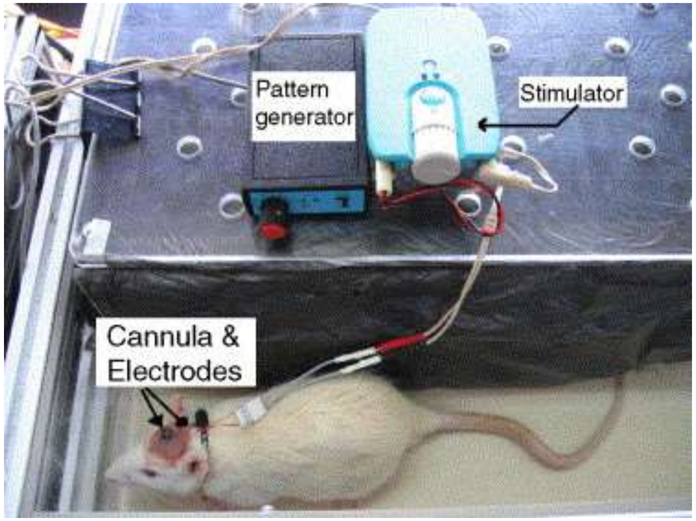
→ Clinical + Home-based Training will be ideal



Amanda G Thrift, Dominique Cadilhac, Tharshanah Thayabaranathan, Geoffrey A Donnan, (2014) Global stroke statistics, International Journal of Stroke 9(1):6-18

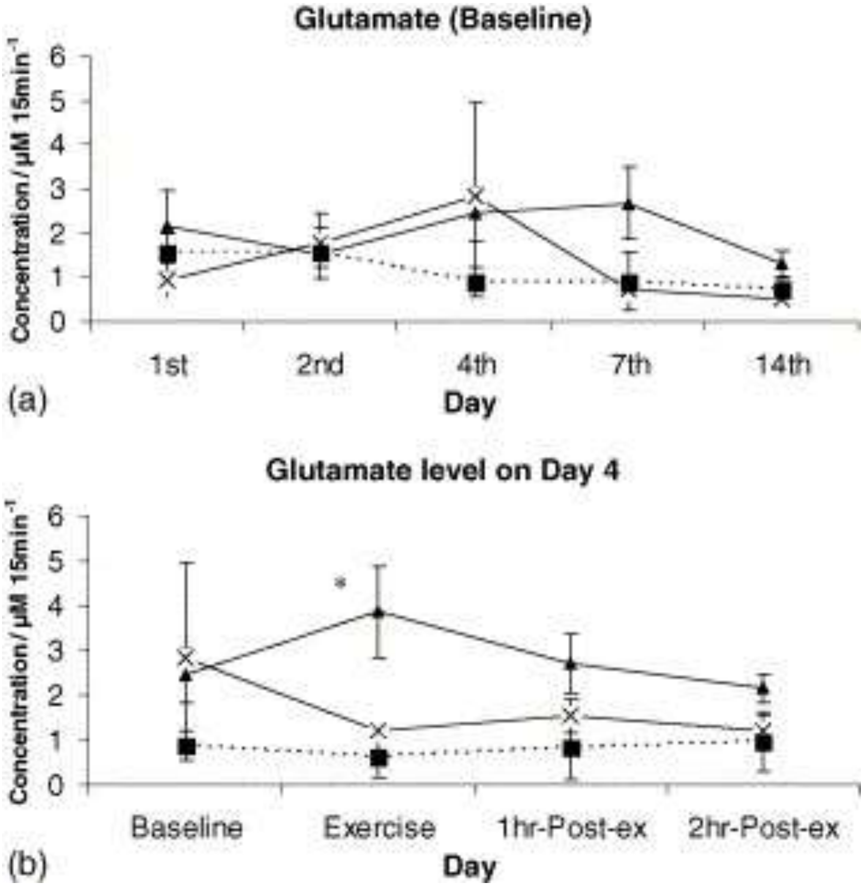
- Only In US in 2006,
  - 6.4 millions people have had stroke
  - 795,000 new and recurrent stroke attacks
  - 137,119 people died of stroke
- In Hong Kong ,
  - Increasing prevalence per year : 11,062 (1981) → 25,053 (2007)
  - Relatively stable mortality rate of about 3,000
  - More people living with disability due to Stroke

Brain neuroplasticity after stroke?



Neurochemical effects of exercise and neuromuscular electrical stimulation on brain after stroke: A microdialysis study using rat model

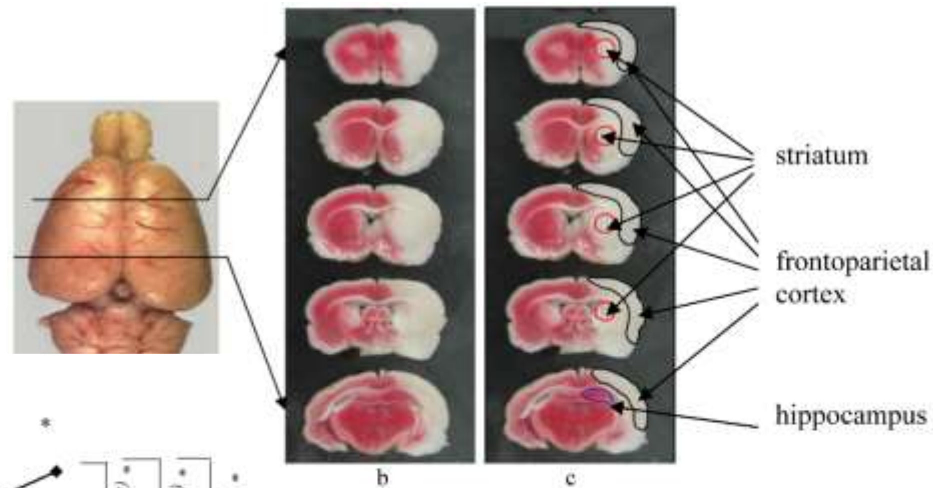
Leung LY, Tong KY,et al. Neuroscience Letters 2006

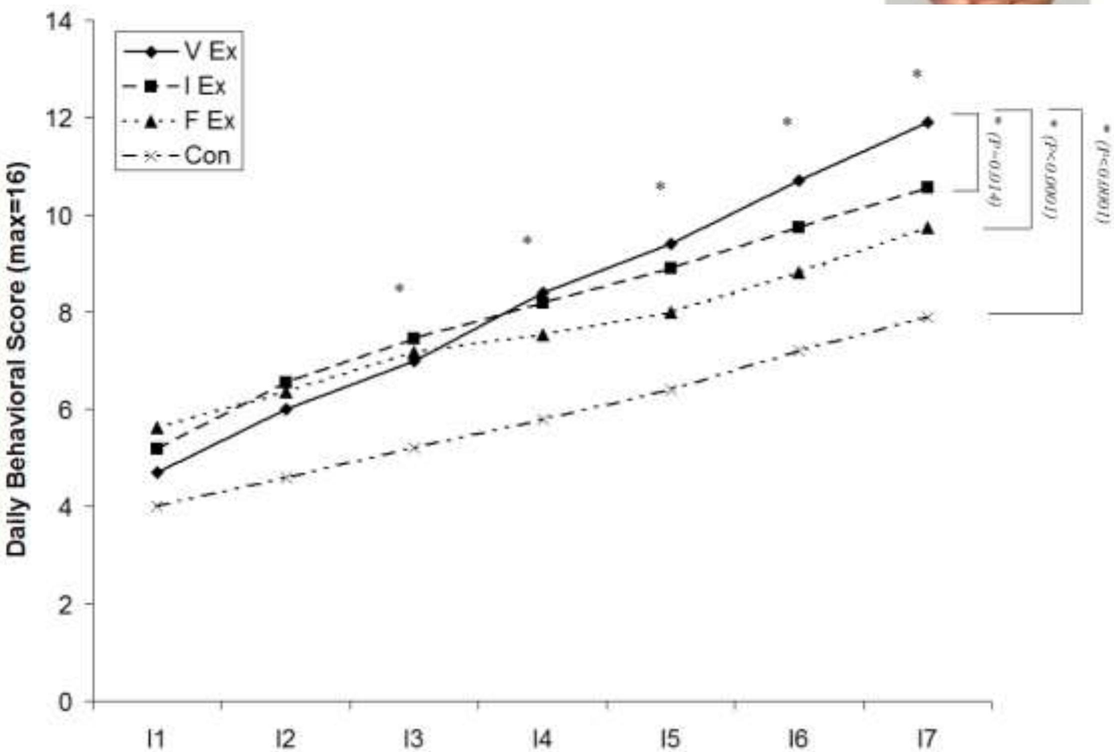


(a) Basal concentrations of glutamate of NMES group (×), Control group (■) and EX group (▲) over the 14 days. Data was expressed in μM 15 min^{-1} ± S.E.M. (b) The change of glutamate level of NMES group (×), Control group (■) and EX group (▲) on Day 4 after MCAo. Data was expressed in μM 15 min^{-1} ± S.E.M. * $p < 0.05$ compared between a particular time point with baseline level in a particular group.

[The effects of voluntary, involuntary, and forced exercises on brain-derived neurotrophic factor and motor function recovery: a rat brain ischemia model] Z Ke, SP Yip, L Li, XX Zheng, KY Tong
PloS one 6 (2), e16643, 2011

- Behavioral Score

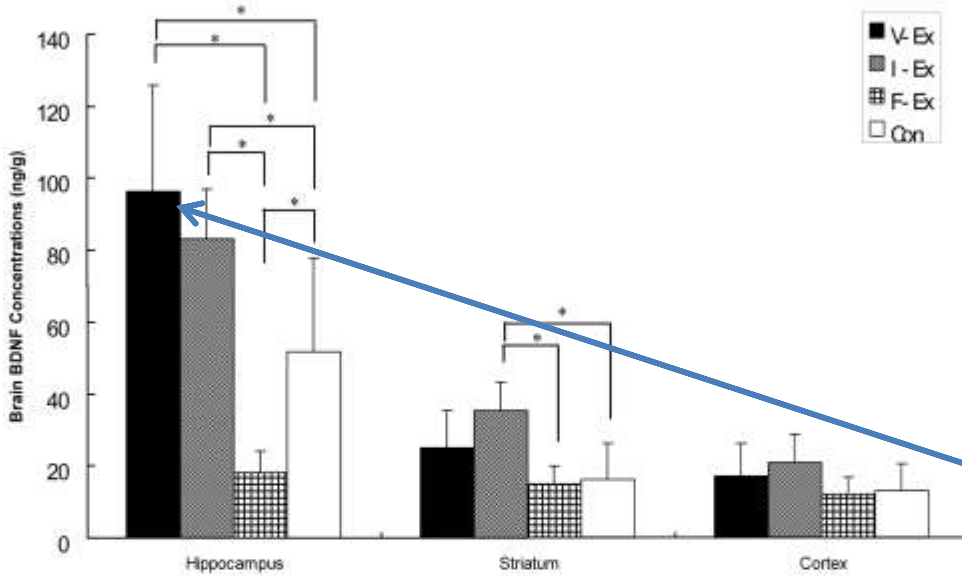




Voluntary Exercise has better recovery in day 7

BDNF

Good for the Brain

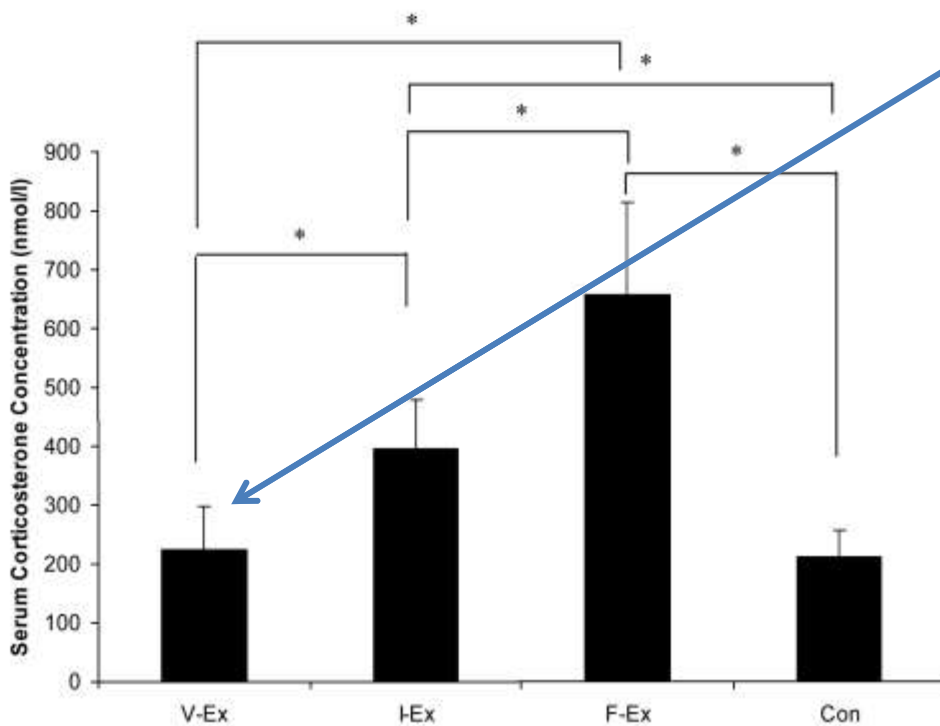


Cortico-sterone

∝

STRESS

Bad for the Brain



Voluntary Exercise is Good for the Brain & hasn’t increased the stress

Trend of Exoskeleton Robotics

Gait Trainer from Germany (2006-08)

PolyJbot Robot Tower (2008, HK)

Hand of Hope (2011, HK)

Ankle Robot, Knee Robot (2016, HK)

Soft robot,Shoulder Robot (2017-ongoing)

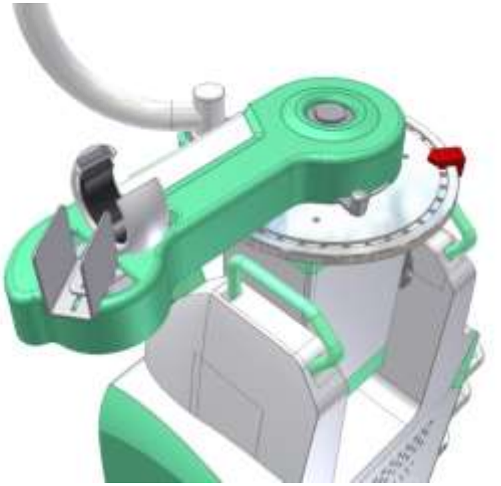
Hong Kong TVB Video 2018 July on our latest Soft Robotics Hand

http://news.tvb.com/local/5b3f9ca7e60383d53d0f02bc?lang=chs

Hong Kong Upper and Lower Limb Rehabilitation Robot using Human Intention (EMG) (2008)

Wrist joint

Elbow joint



Knee joint

Ankle joint

Hu X, Song R, Tong KY, Zhou W. Myoelectrically controlled wrist robot for stroke rehabilitation. *J Neuroeng Rehabil* 2013 Jun 10;10:52. [Link]

Key findings
(Human Intention-driven + Robot = Brain motor relearning)

- The <u>myoelectrically controlled robot-aided training</u> improved the motor impairment after the training for both the wrist and elbow joints in muscle coordination and spasticity reduction, which could be maintained for 3 months.
- The <u>passive mode training</u> mainly reduced the spasticity in the wrist flexor, but did not contribute to the muscle coordination improvement.

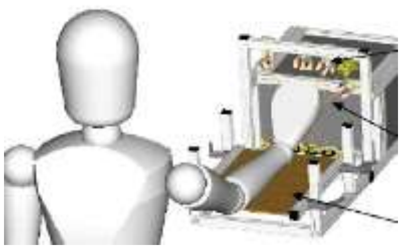
Hu XL, **Tong KY***, et. al. (2009), A Comparison between Electromyography (EMG)-Driven Robot and Passive Motion Device on Wrist Rehabilitation for Chronic Stroke, *Neurorehabilitation and Neural Repair*, 23:837-846

Hu XL, **Tong KY***, et. al., (2009) Quantitative Evaluation of Motor Functional Recovery Process in Chronic Stroke Patients during Robot-Assisted Wrist Training, *Journal of Electromyography and Kinesiology*, 19: 639-50

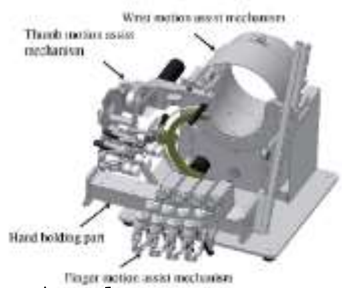
Hu XL, **Tong KY***, Ho SK, Xue JJ, Rong W, Li SW. Wrist Rehabilitation Assisted by an Electromyography-Driven Neuromuscular Electrical Stimulation Robot After Stroke *Neurorehabilitation and Neural Repair* 2014 Dec; 29(8):767-76. [Link]

Hand & Wrist Robots Review

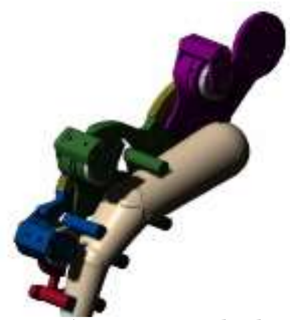
- Robotics training is defined as the use of computers, electronic in mechanical design to help the rehabilitation training process (Cooper et al, 2008).
- Different Design for hand function training



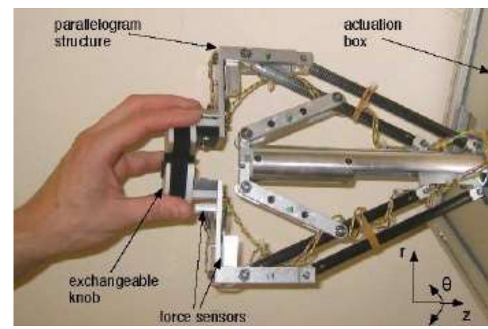
Cable driven robotic system by National University of Singapore (Dovat et al)



Another system uses the subjects' sound side to control robotic hand by Gifu University(Kawassaki et al)



Finger exoskeleton by Northwestern University (Worsnopp et al.)



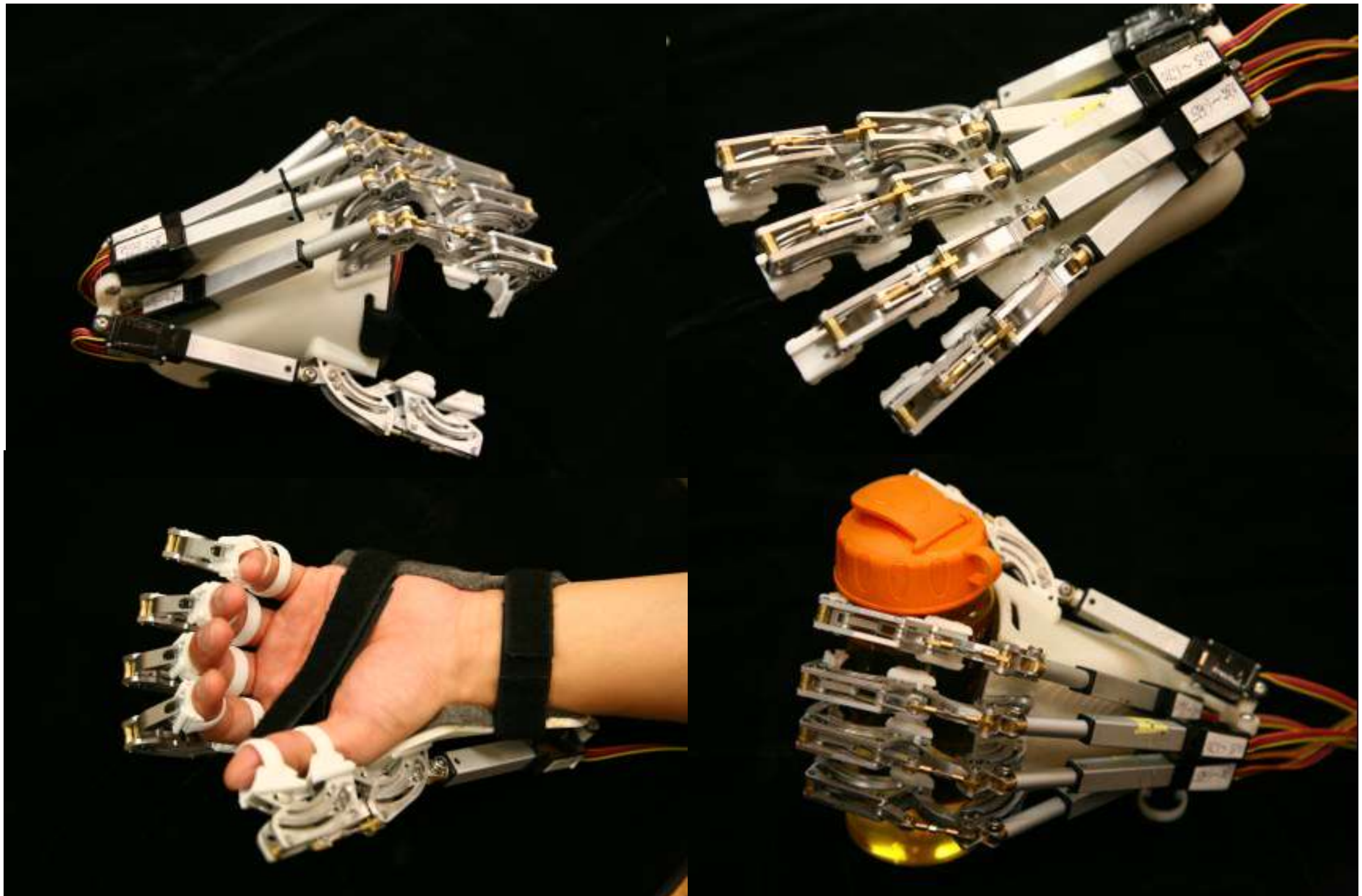
Haptic Knob by ETH Zurich and NUS (Lambercy et al.)

2012 希望之手 – Hand of Hope (license to Rehab-robotics (support Vincent Medical HK IPO 2016)

Raymond Tong joint collaboration with Industrial Centre

https://m.scmp.com/video/hong-kong/2114006/how-hong-kongs-ageing-society-can-benefit-biomedical-engineering
(Video link from South China Morning Post 2017)

Hand Function Task Training Robot



EA Susanto, **RK Tong** ,et al *Efficacy of robot-assisted fingers training in chronic stroke survivors: a pilot randomized-controlled trial*. J Neuroeng Rehabil. (2015) **[Link]**

Movie clips – Subject with Chronic Stroke

Task without Hand robot

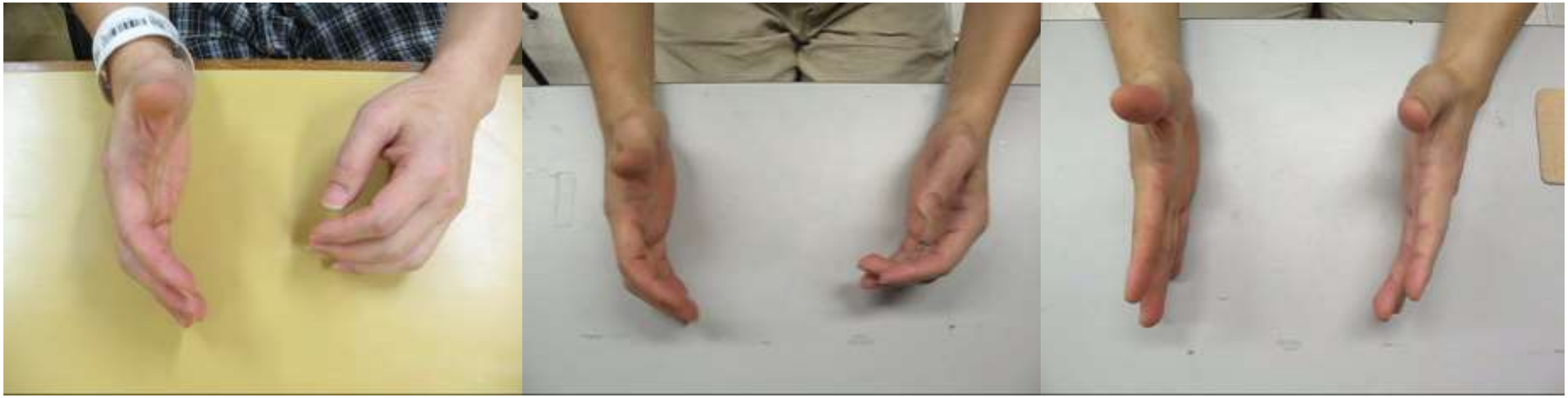
Task with Hand robot

Hu XL, …. **Tong KY**. The effects of post-stroke upper-limb training with an electromyography (EMG)-driven hand robot. *J Electronmyogr Kinesiol* 2013 Oct;23(5):1065-74. [Link]

Lu Z, **Tong K**, Shin H, Li S, Zhou P, Advanced Myoelectric Control for Robotic Hand-Assisted Training: Outcome from a Stroke Patient, *Frontiers in Neurology, 2017, 8*[Link]

Pre- and Post 20-session Training on a **Subacute Stroke Suvivor** (Significant Improvement in Hand Opening)

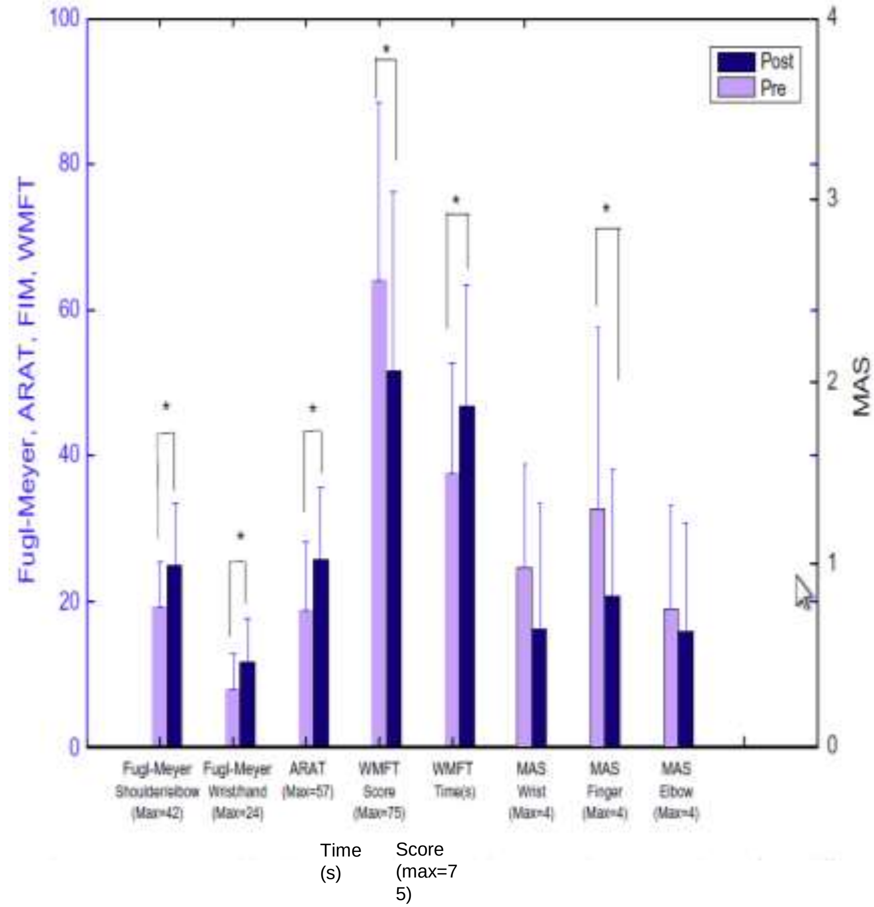
Stroke Type	**Affected Side**	**Gender/Age**	**Onset Time**
Ischemic	Left	M/50	4 weeks



Pre-training, 10-session training, 20-session training

Clinical Data from Chronic Stroke Subjects before and after 20-session training

It is found that significant motor improvements after the training could be captured by the FMA (shoulder&elbow (S&E), and wrist&hand(W&H), and ARAT. The improvement in ARAT score mainly reflects the motor recovery in hand and finger functions. The increased FMA scores suggest the motor improvement in the whole upper limb after the training. Significant reduction in spasticity of the fingers using MAS.



XL Hu, **KY Tong**, et al *The effects of post-stroke upper-limb training with an electromyography (EMG)-driven hand robot.* Journal of Electromyography and Kinesiology (2013) **.** **[Link]**
EA Susanto, **RK Tong** ,et al *Efficacy of robot-assisted fingers training in chronic stroke survivors: a pilot randomized-controlled trial*. J Neuroeng Rehabil. (2015) **[Link]**

Existing robotic system


Triggered by Joystick or Trunk Movement



Bulky

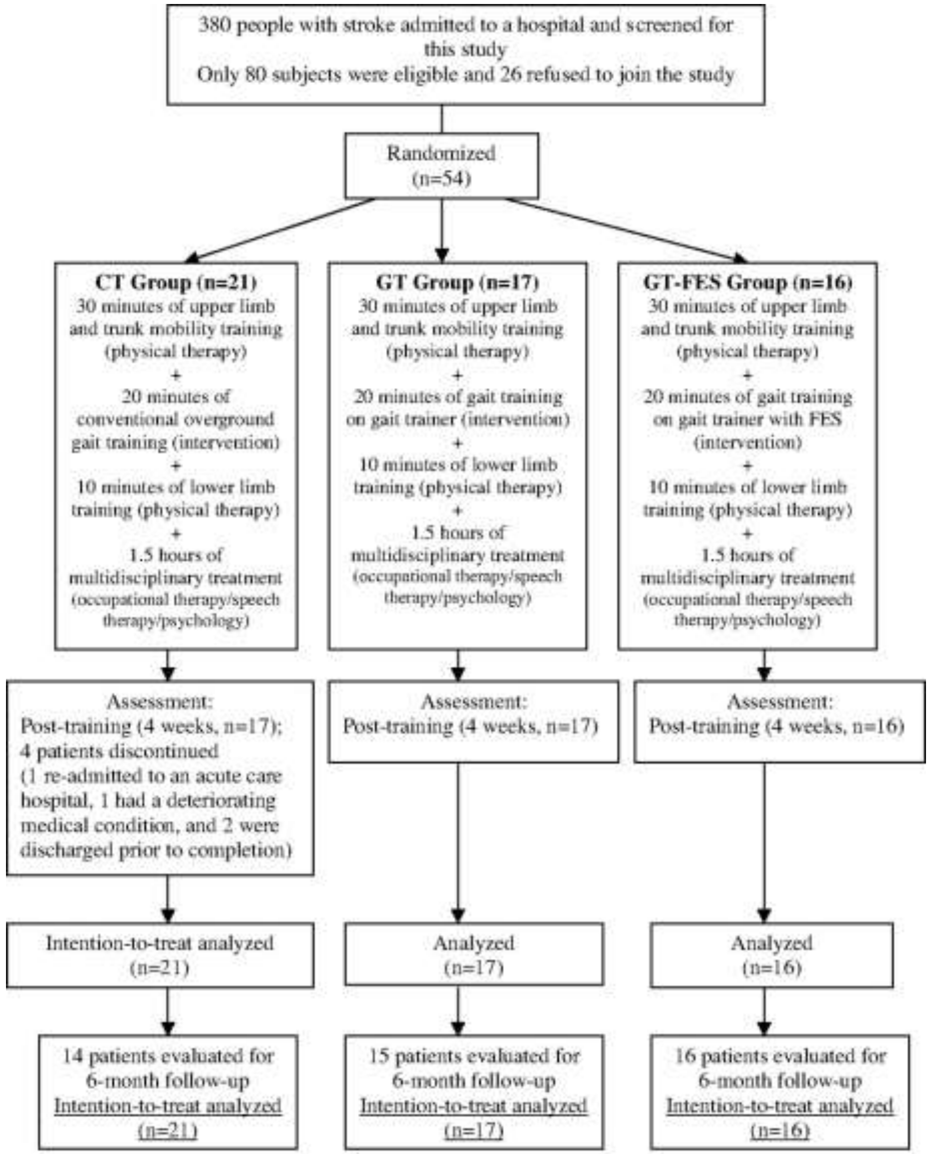
Heavy （15-20kg） =

Expensive

Figure 1. Picture of one GT-FES subject undergoing gait training on the gait trainer.

Maple F.W. Ng et al. Stroke. 2008;39:154-160

Figure 2. CONSORT flowchart of the training programs.



Independent Walker using FAC

FAC	CT	1.4±0.7	2.5±1.2	3.0±1.3	0.008*	**4 weeks:**
	GT	1.3±0.9	3.2±0.8	4.0±1.0		CT vs GT (0.096) [0.67]
	GT-FES	1.3±0.5	3.4±0.9	4.2±0.8		CT vs GT-FES (0.024*) [0.78]
						GT vs GT-FES (0.819) [0.20)
						6 months:
						CT vs GT (0.018*) [0.88]
						CT vs GT-FES (0.003*) [1.13]
						GT vs GT-FES (0.766) [0.24]

Thirteen of the 16 subjects (81.3%) in the GT-FES group could walk independently with FAC≥4 at the 6-month follow-up. Only 9 of the original 21 subjects (42.9%) in the CT group and 11 of the original 17 (64.7%) in the GT group reached this level.

Smart Exoskeleton Robotic Leg

Patient wears it on his shank/thigh/hip

Effective

Nature walking

Improve balance

Light weight（500-800g）

0.5L

Smart Intelligent System to automatically identify user intention

- The robot can sense the gait pattern of the user by using embedded motion sensors and force sensors, and then determine the walking intention.
- The robot can provide power assistance to actuate the ankle, knee and hip joint movement during walking on the floor, upstairs and downstairs, with proper feedback to enhance the quality and speed of walking pattern. The system design is portable and light-weight. Stroke patients can wear this exoskeleton robot to regenerate walking function, better to encourage patients walk more frequently.

Tong KY, Lau HY, Zhu H. Support Vector Machine for Classification of Walking Conditions of Persons After Stroke with Dropped Foot. *Hum Mov Sci* 2009 Aug;28(4):504-14. [Link]
Tong KY and Lau HY. The reliability of using accelerometer and gyroscope for gait event identification on persons with dropped foot. *Gait Posture* 2008 Feb;27(2):248-57. [Link]
Tong KY, Lau HY, Zhu H. Support Vector Machine for Classification of Walking Conditions Using Miniature Kinematic Sensors. *Med Biol Eng Comput*. 2008 Jun;46(6):563-73. [Link]

Novelty in Ankle Robot

1. Gear transmission system

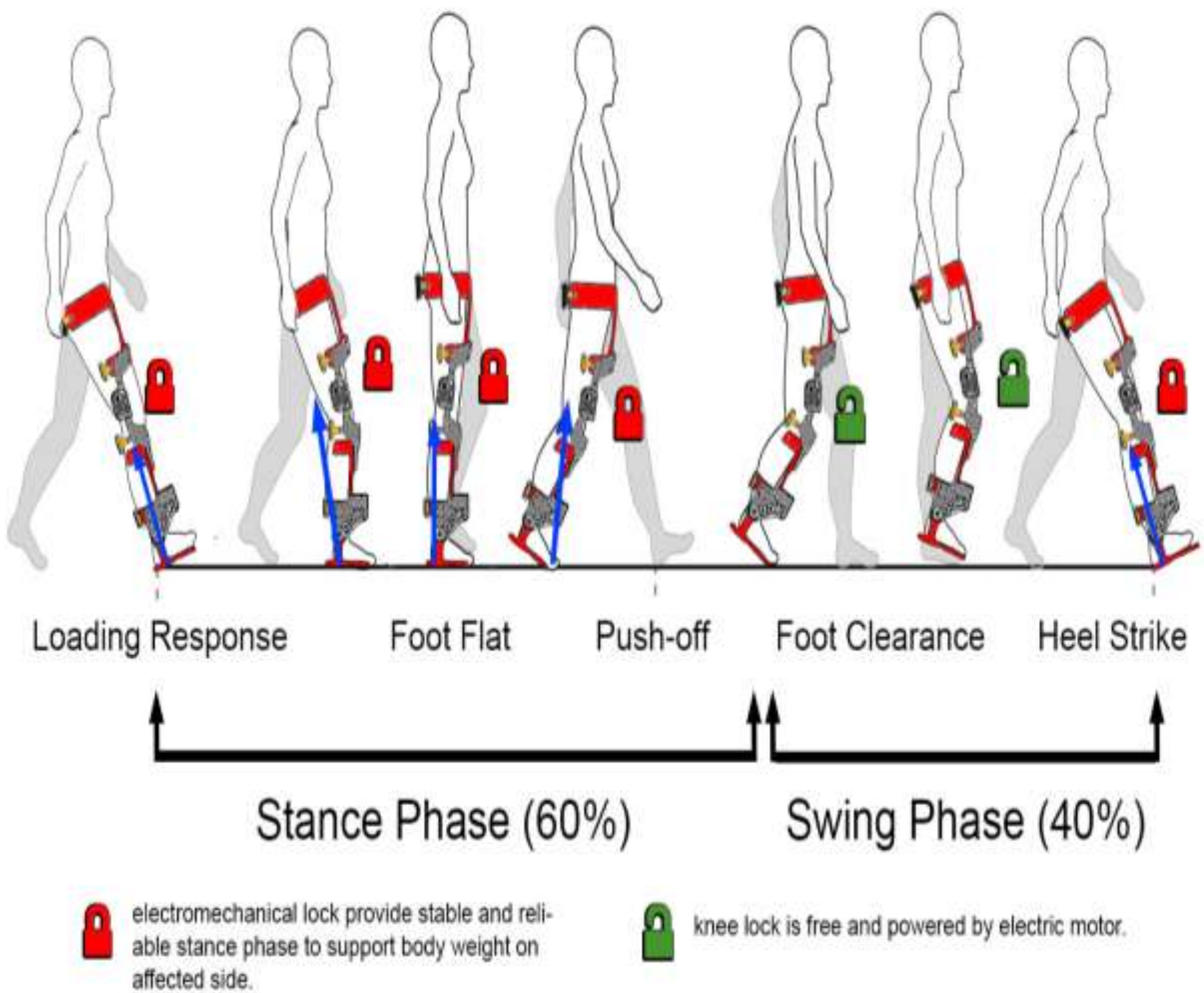
   - can facilitate large force with a small motor.

2. Intelligent based on the sensors feedback.

Gear Transmission system

Force and Motion sensors

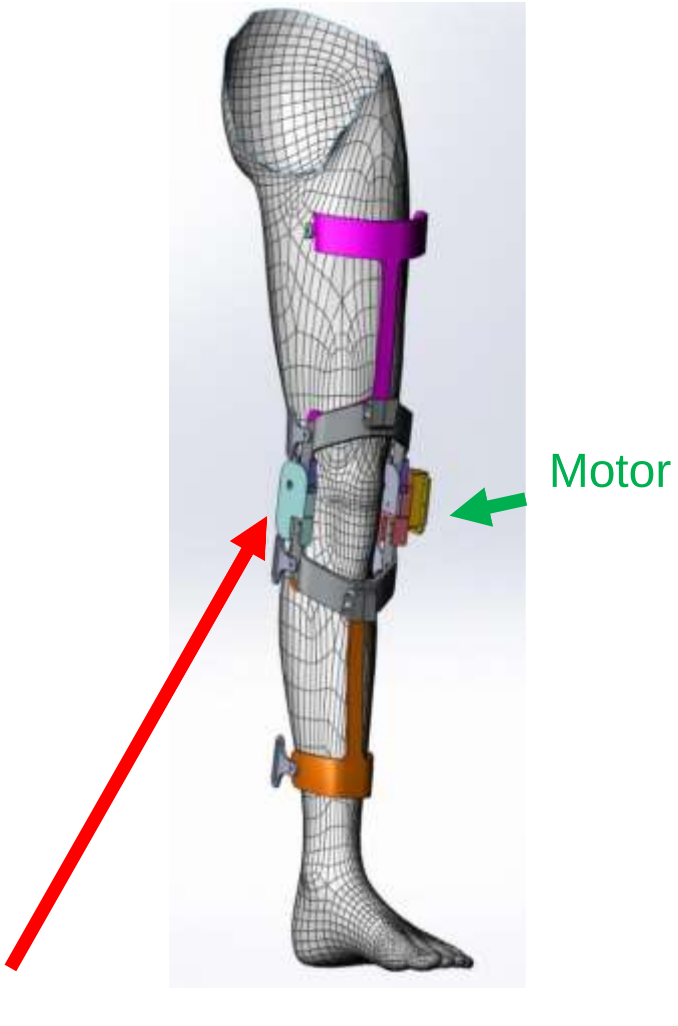
Novelty in Knee Robot



Electromechanical Lock with Motor

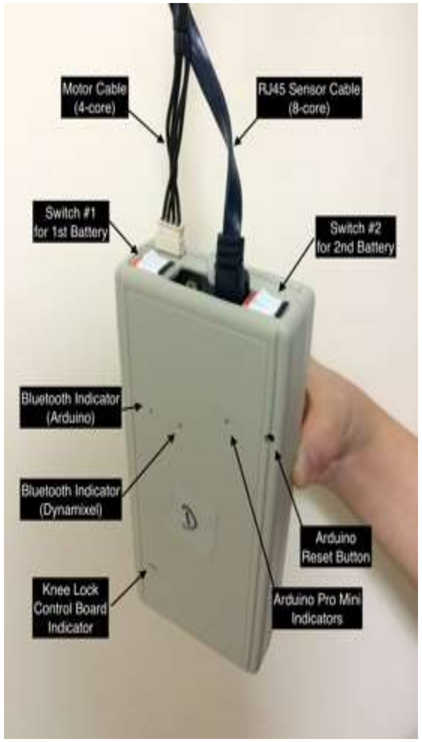
Interactive control

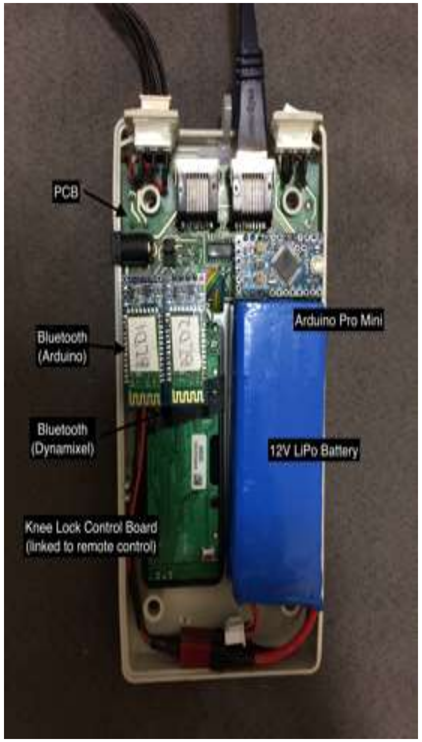
- An interactive exoskeleton knee system for gait training of a user, the system comprising: an exoskeleton framework with thigh and shank linkage on an unilateral side; a sensor system; force sensors; a motor; a mechanical lock system; a control box; a control algorithm to integrate motor and lock synchronization.



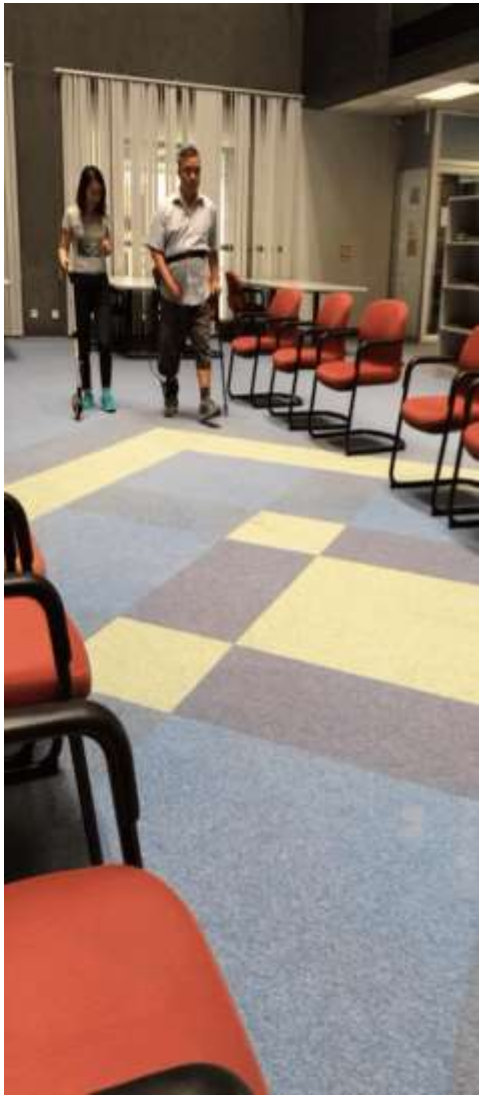
Electronic circuit design

(just need to carry this one and the rechargeable battery can last for 2 days)





It is very unique for rehabilitation purpose :
stroke survivors can use it indoor as well as outdoors for rehabilitation training.



Clinical results : 20 Stroke Patients
(20 sessions training)

% of patients with improvement exceeding Clinical Significant Value

Function

Walking speed

Clinical results (20 sessions of training (1 hour with robotic system)

- Ankle robot

10 stroke subjects in ankle robot study

1. 30% of them improved in FAC (Functional Ambulation Category for walking independency).
2. 70% of them improved in FMA-LE (Fugl-meyer Assessment – Lower Extremity).
3. 40% of them improved in MAS (Modified Ashworth Score for Spasicity).
4. 40% of them improved in BBS (Berg balance scale).
5. 80% of them improved in 10 MWT (10 meter walk test).
6. 80% of them improved in 6 MWT (6 min walk test).

- Knee robot

10 stroke subjects in knee robot study

1. 40% of them improved in FAC.
2. 40% of them improved in FMA-LE.
3. 70% of them improved in MAS.
4. 40% of them improved in BBS.
5. 50% of them improved in 10 MWT.
6. 100% of them improved in 6 MWT.

Clinical training for 20 sessions with 20 stroke subjects

- Ankle Robot

- Knee Robot

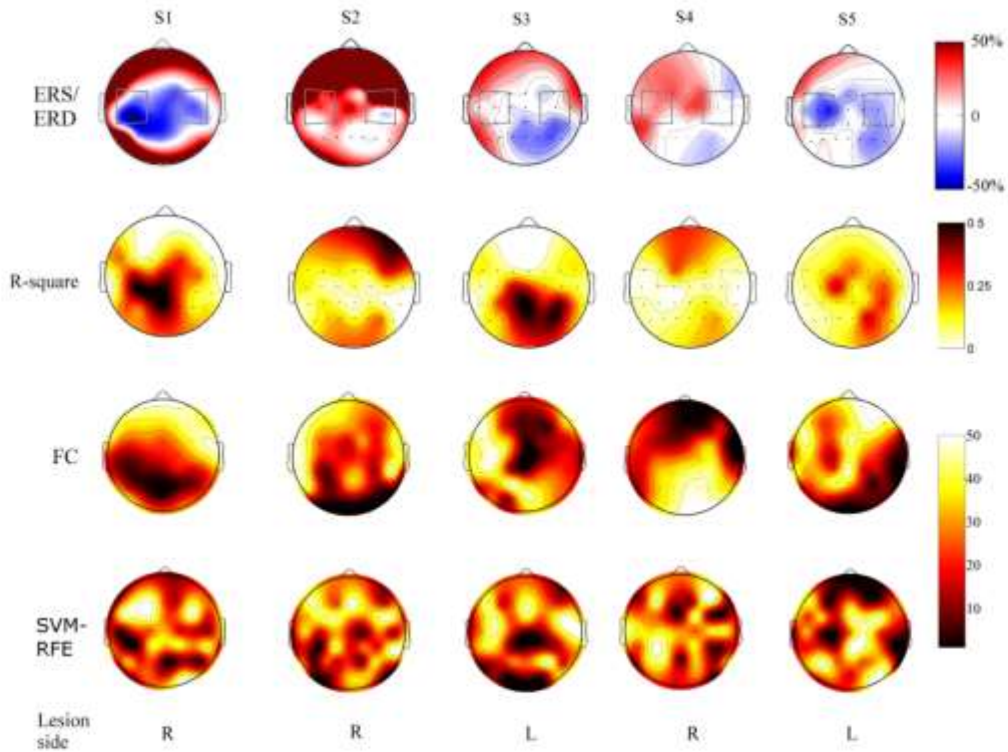
Stroke patient with dropped foot

Ankle robot

It is very unique for rehabilitation purpose :
stroke survivors can use it indoor as well as outdoors for rehabilitation training.

EEG biofeedback ?

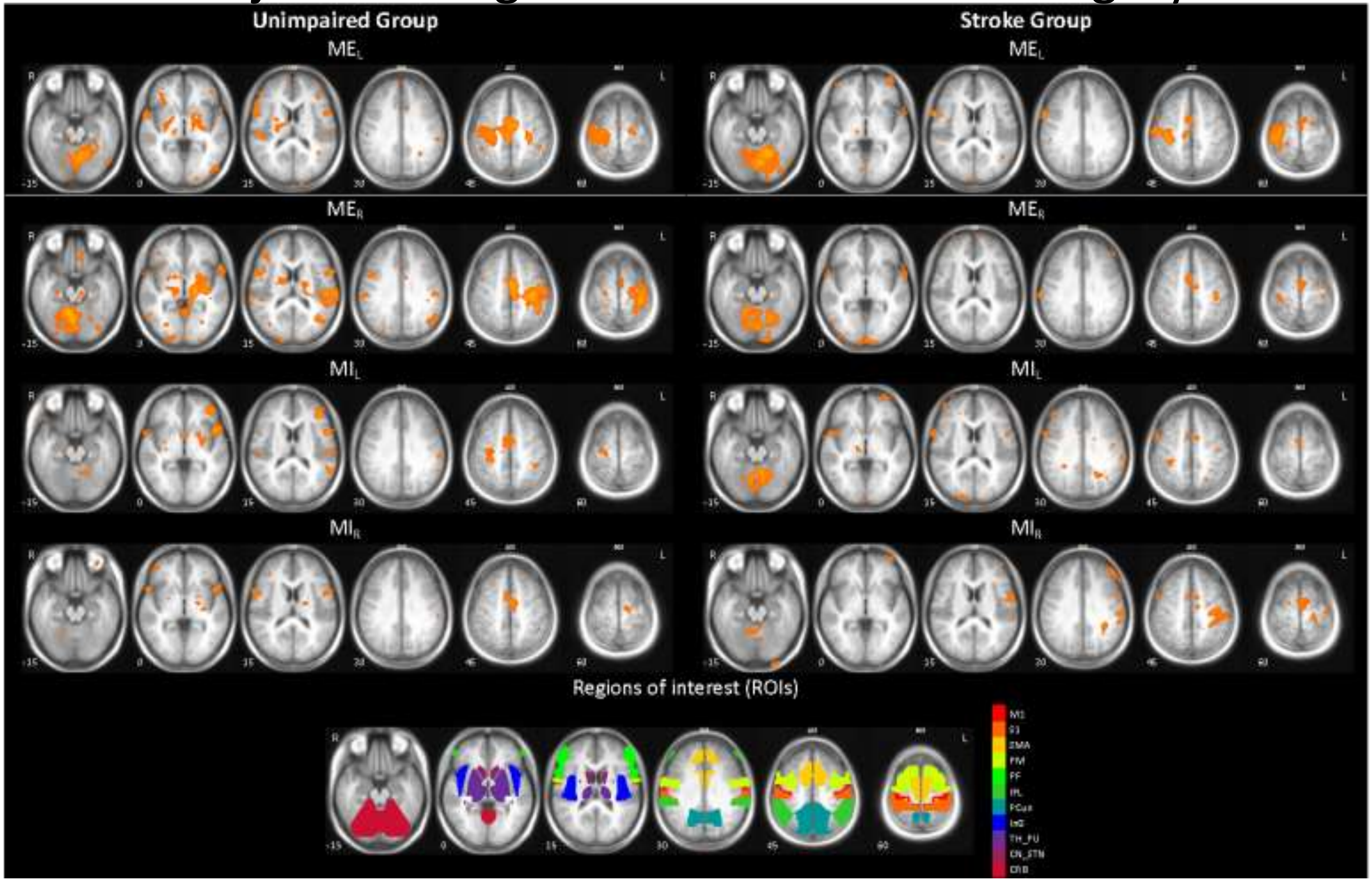
Brain Neuroimaging using **EEG** from stroke subjects



The average ERD and R-square topographies of all 20 sessions of training of the subjects, and their channel selection ranking distribution on the first day of training. ERD/ERS topographies were shown in the first row. The squares indicate the sensorimotor area. Blue color represented ERD and red color represented ERS. R-square topographies are shown in the 2nd row. The distributions of the ranking of the channel in FC and SVM-RFE were shown in the 3rd and 4th row respectively. Darker the color represents a higher ranking

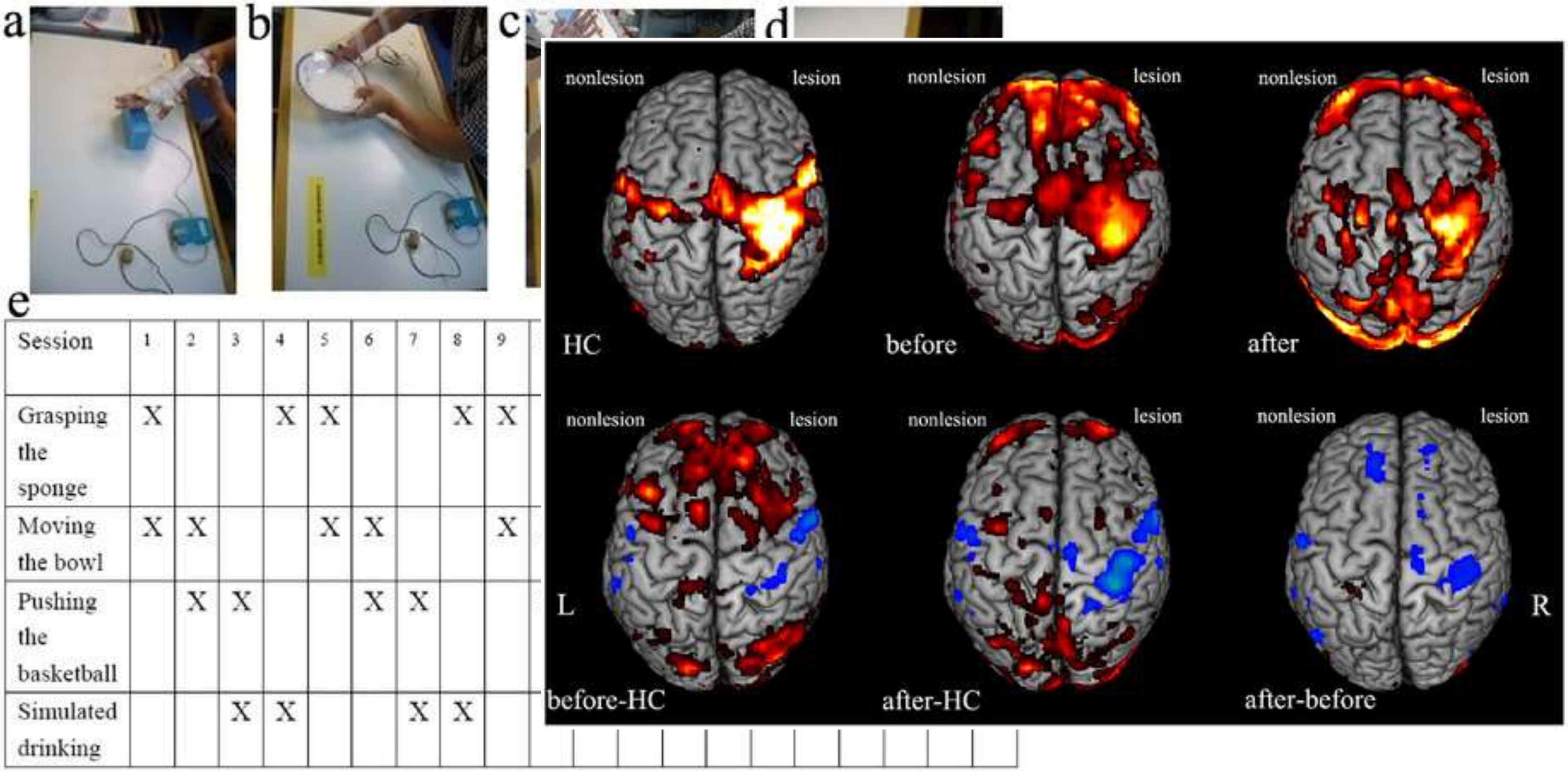
(Tam WK, **Tong KY**, et al. 2011 IEEE TRANSACTIONS ON NEURAL SYSTEMS AND REHABILITATION ENGINEERING, VOL. 19, NO. 6,).

MRI Comparison between Stroke and Unimpaired Subjects during Motor Execution or Imagery



(Wong WW, Chan ST, Tang KW, Meng F, **Tong KY**, 2013 Brain Injury.)

[A longitudinal study of hand motor recovery after sub-acute stroke: a study combined fMRI with diffusion tensor imaging](#)W Wei, L Bai, J Wang, R Dai, RK Tong, Y Zhang, Z Song, W Jiang, C Shi, ...
PloS one 8 (5), e64154, 2013



Session	1	2	3	4	5	6	7	8	9
Grasping the sponge	X			X	X			X	X
Moving the bowl	X	X			X	X			X
Pushing the basketball		X	X			X	X		
Simulated drinking			X	X			X	X	

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