# Applications of fNIRS in Neuroscience

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# Let's begin, shall we

**Another talk, I know…**

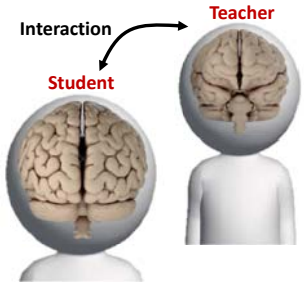
**You are ready to yawn,**
**Oh, you are doing now….**

**No one dares to say sometimes "Learning" is boring and frustrating…**
**But it is true….**



# Complex Learning Process

- Two-person **Educational Neuroscience**
- The teacher-student interaction





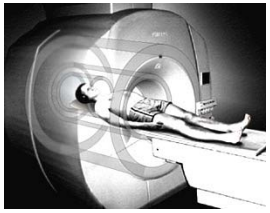
**Teaching and Learning Brain??**



# New Tool for Neuroscience

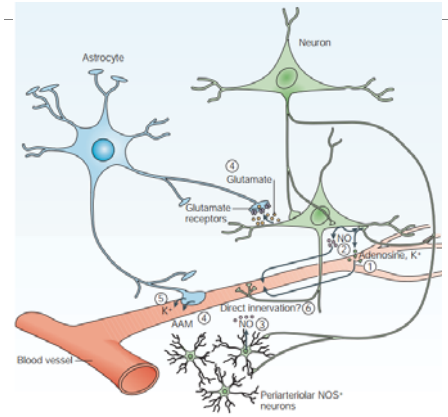
Functional Near-Infrared Spectroscopy (fNIRS)
- Neuroscience tools
- Principles of fNIRS
- Applications in neuroscience
- Perspectives of fNIRS future

# Monitoring Brain Activity

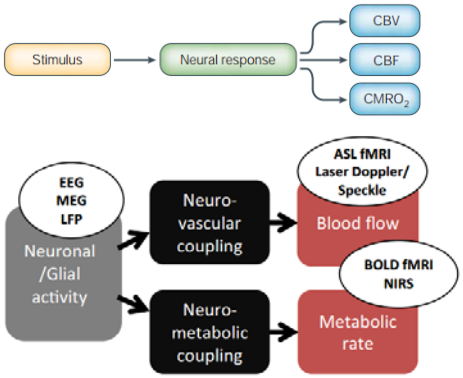
| EEG/MEG | fMRI | fNIRS |
|---|---|---|
|  |  |  |
| • **High temporal resolution**<br>• **Neural activity**<br>• Superficial cortex<br>• **Semi-open/close environment**<br>• **Low cost**<br>• Physiological noise<br>• Electronic noise | • Low temporal resolution<br>• BOLD signal<br>• **Superficial & deep cortex**<br>• Close environment<br>• High cost<br>• **High spatial resolution**<br>• **High tissue contrast**<br>• Magnetic and posture limitation | • **High temporal resolution**<br>• Hemoglobin oxygenation<br>• Superficial cortex<br>• **Open environment**<br>• **Low cost**<br>• **Wearable system** |



# Neurovascular Coupling



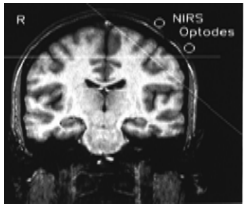

D'Esposito et al, Nature Reviews Neuroscience, 2003.



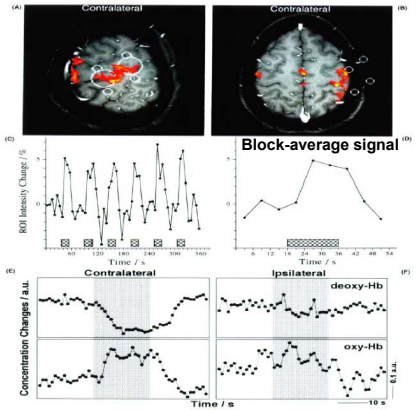

Huneau et al, Frontiers in Neuroscience, 2015.



# fNIRS vs. fMRI (finger taping)



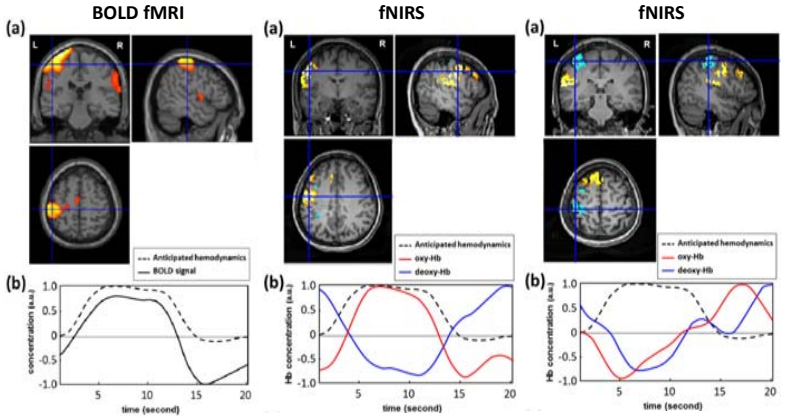

- **Decreases in deoxy-Hb, which reduce the microscopic susceptibility effects, yield fMRI BOLD signal increases.**

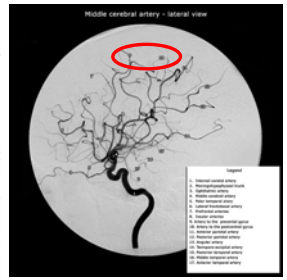



JCBFM. 1996, 16:817-826.



# fNIRS vs. fMRI (hand grasping)



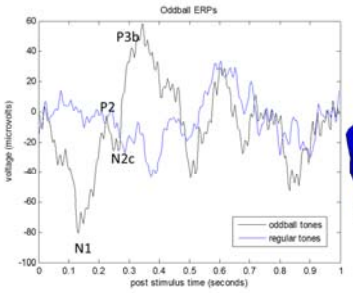



Lu, et al, 2013 EMBC.

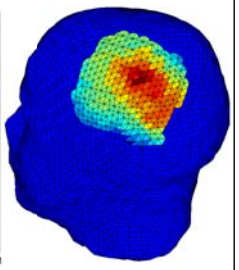
# fNIRS vs. EEG (oddball task)

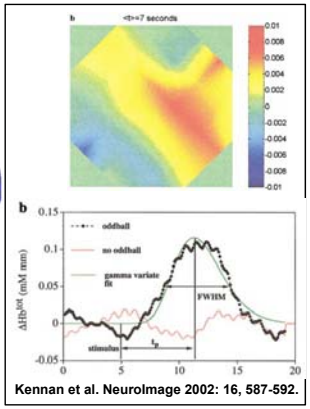
fNIRS + Mindo

EEG at Pz




fNIRS
4.2s after stimuli






Kennan et al. NeuroImage 2002: 16, 587-592.

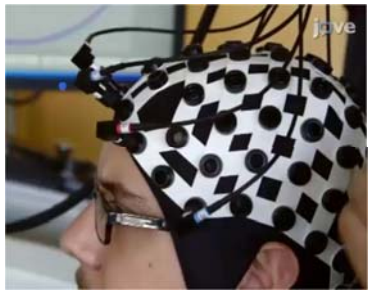
1000 Hz tone

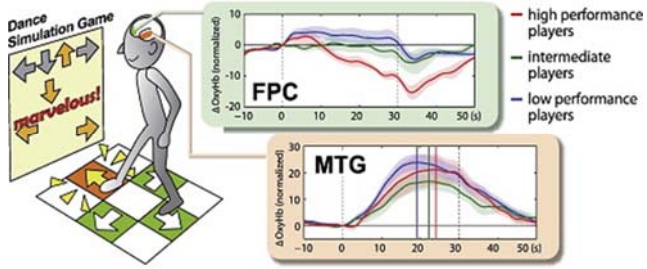
2000 Hz oddball



# Open Environment

**Frontopolar cortex (FPC):** top-down regulatory mechanisms of motor behavior;
**Middle temporal gyrus (MTG):** bottom-up integration of visual and auditory cues.



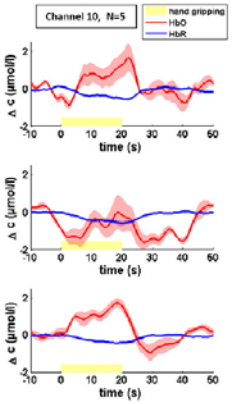

J. Adam Noah, Journal of Visualized Experiments, 2015.

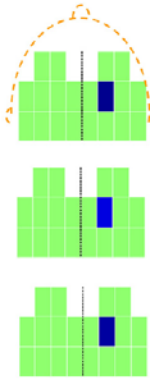
NeuroImage 85 (2014) 461–470.



# Open Environment

NeuroImage 85 (2014) 64–71

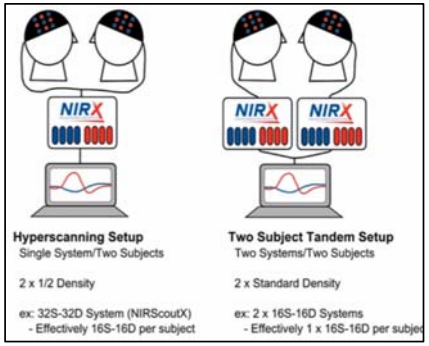



Left-hand gripping



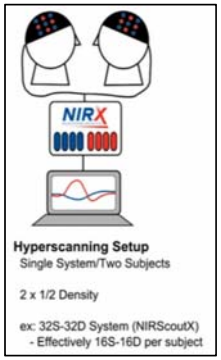
# Interaction/Competition

Social cognition is fundamentally different when we interact with others rather than merely observing them.




NIRx Medical Technologies, http://nirx.net/nirscout/

# Interaction/Competition

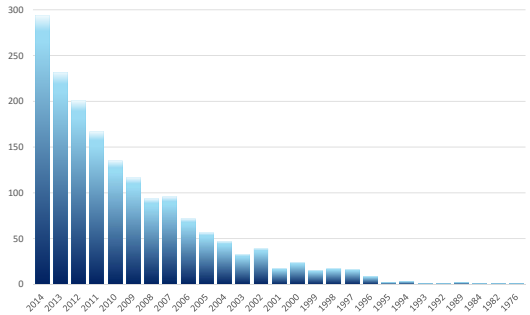


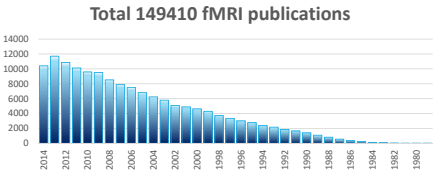


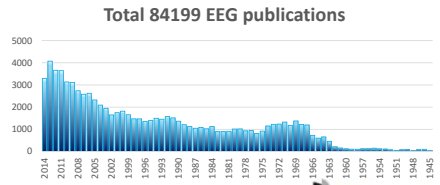
NIRx Medical Technologies
http://nirx.net/nirscout/



# fNIRS Publications

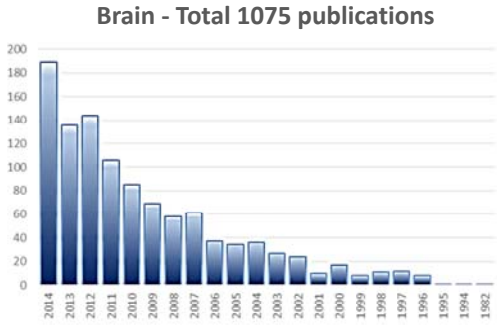


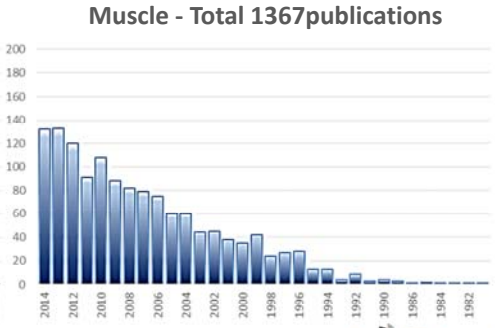






# fNIRS Publications

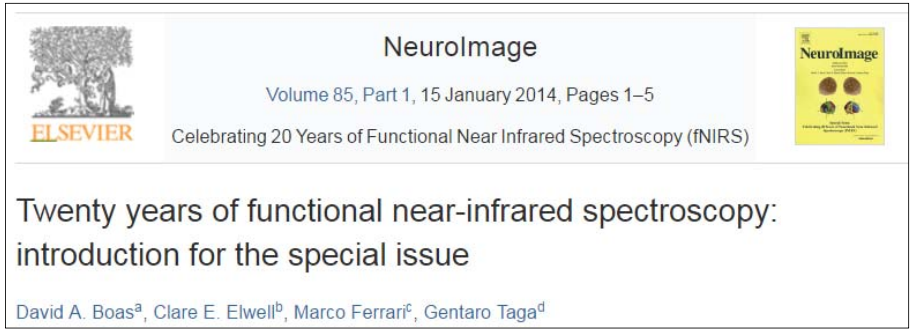





# NeuroImage Special Issue, 2014

http://www.sciencedirect.com/science/journal/10538119/85/part/P1



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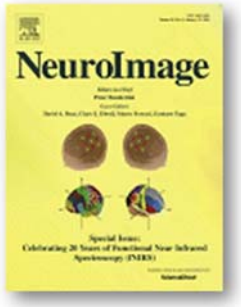
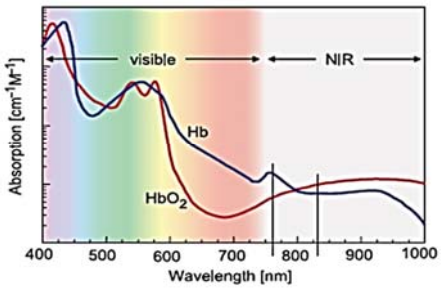



- Introduction (1 article)
- Instrumentation (4 articles)
- Analysis Methods (15 articles)
- Brain Development (10 articles)
- Cognitive Science (7 articles)
- Motor, Balance, and Gait (7 articles)
- Psychiatry (6 articles)
- Neurology, Aging, and Anesthesia (9 articles)

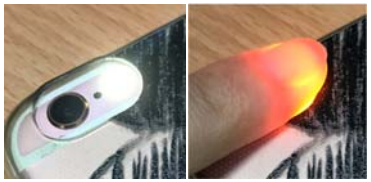
59 articles, 696 pages in total.



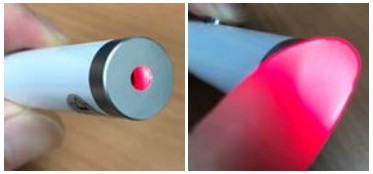
# Tissue Migration and Absorption




$$\mu_{780nm} = \varepsilon_{HbO_2}(780nm)\times c_{HbO_2} + \varepsilon_{Hb}(780nm)\times c_{Hb}$$
$$\mu_{820nm} = \varepsilon_{HbO_2}(820nm)\times c_{HbO_2} + \varepsilon_{Hb}(820nm)\times c_{Hb}$$



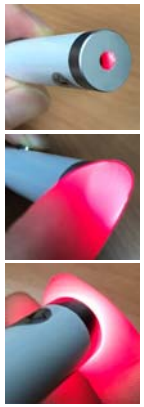
lower absorption within Near-infrared wavelength.

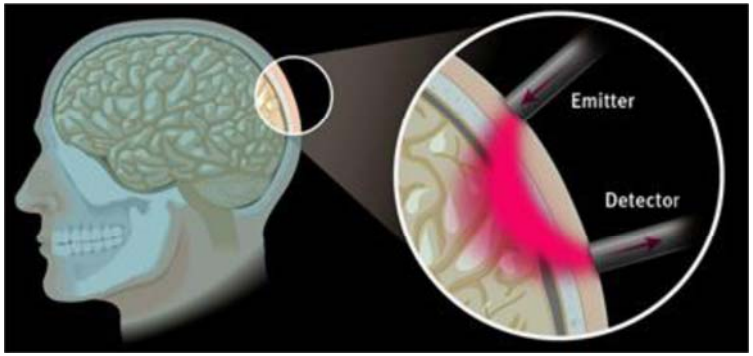


Near-infrared photons perform diffusive motion.



# Diffusive Motion

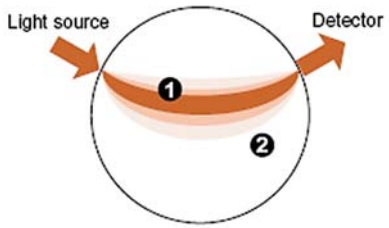




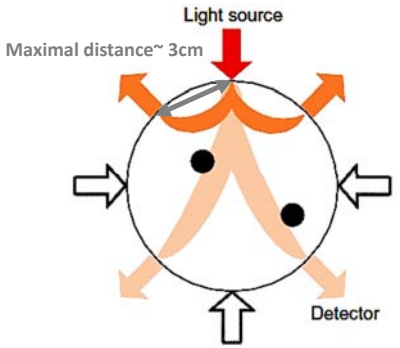

Absorption and scattering



# Source-Detector Arrangement

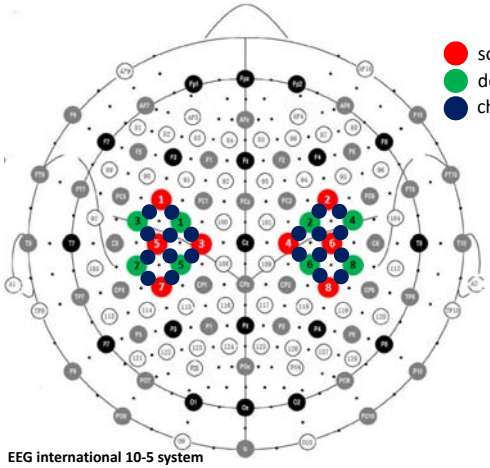



Diffusive motion
Banana-shape distribution



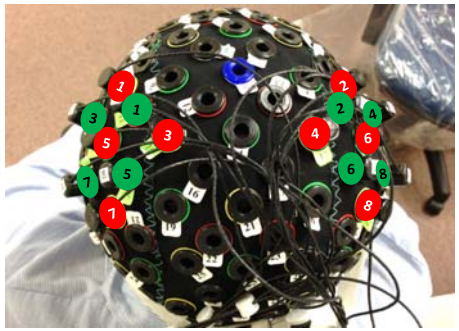

Spatial encoding ➔ fire one source at one cycle

# Source-Detector Arrangement

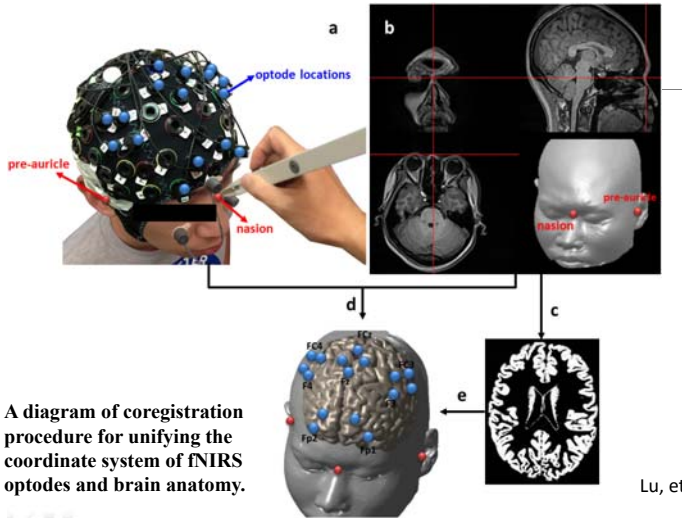


EEG international 10-5 system

sources
detectors
channels





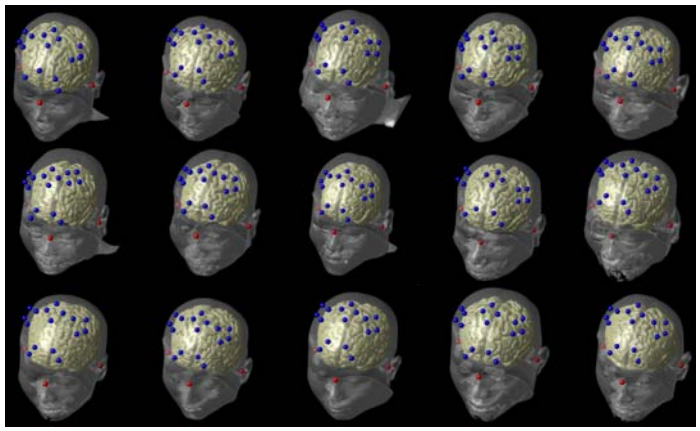



**A diagram of coregistration procedure for unifying the coordinate system of fNIRS optodes and brain anatomy.**

Lu, et al. PLoS One, 2015.



# Confirm Channel Locations





# fNIRS Instruments

**< portable/movable >**

ISS instrument

NIRx NIRScount

Hitachi ETG-7100 system


DYNOT system

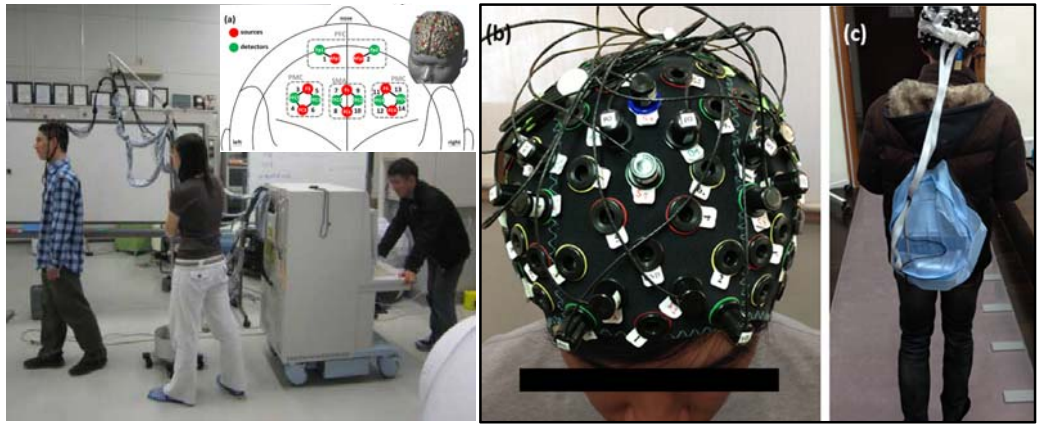
**< wearable >**


NIRSport

# Size, Does it matter? (2009~2011)



# Size, Does it matter? (2013~2016)





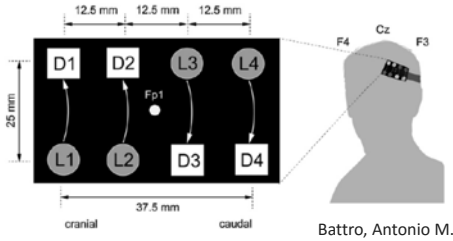

# What Can We do with fNIRS?

- Brain Development
- Cognitive Science/**Educational Neuroscience**
- Motor, Balance, and **Gait**
- **Neurorehabilitation**
- **Psychiatry**
- **Neurology**, Aging, and Anesthesia

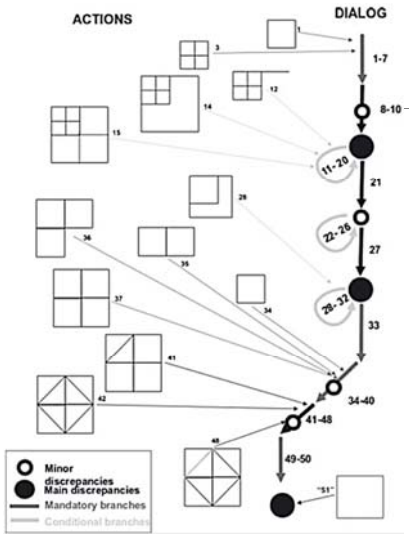


# Educational Neuroscience

- The teacher-student interactions, fNIRS hyperscanning
- **A classical teaching model, Socratic dialogue (Meno by Plato).**
  - **How to double the area of a square?**
  - 50 questions to support the student in discovering the solution by self-elaboration.

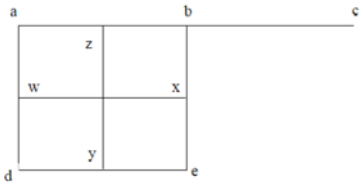



Battro, Antonio M., et al. *Mind, Brain, and Education* 7.3 (2013): 177-181.
Holper, Lisa, et al. *International Journal of Educational Research* 59 (2013): 1-10.




# Socratic dialogue

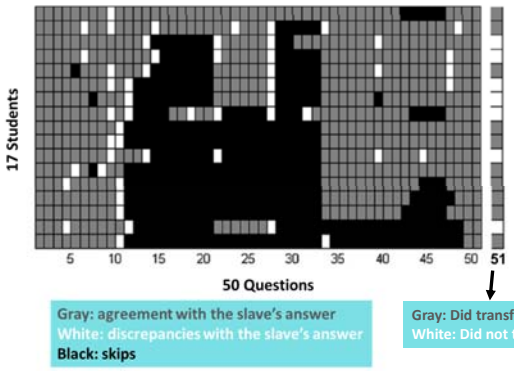
**Q1. Tell me, boy, do you know that a figure like this is a square?**
*The interviewer draws and shows a 2x2 square (abed in Fig.).*
**Q2. And you know that a square figure has these four lines equal?**
*The interviewer points to all the four lines (lines ab, be, ed, da in Fig.).*
**Q3. And these lines which I have drawn through the middle of the square are also equal?**
*The interviewer points to the "middle" lines (zy and wx in Fig.).*

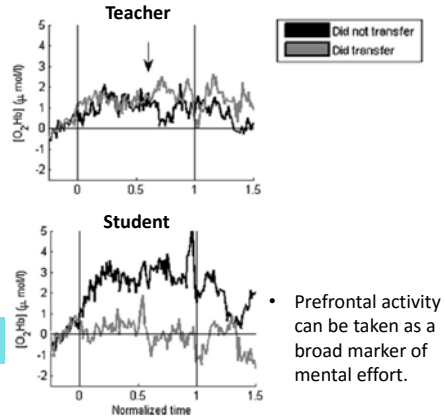



Goldin, Andrea P., et al. *Mind, Brain, and Education* 5.4 (2011): 180-185.



# Students, who successfully transferred the knowledge, showed less prefrontal activation



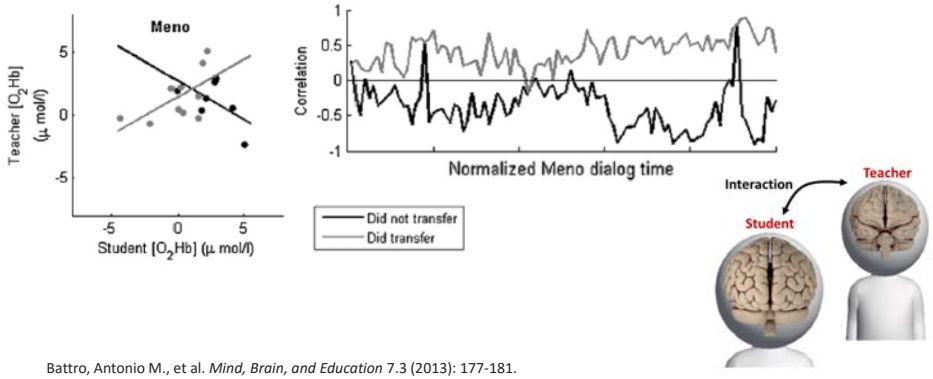




- Prefrontal activity can be taken as a broad marker of mental effort.

Battro, Antonio M., et al. *Mind, Brain, and Education* 7.3 (2013): 177-181.



# Student and Teachers 'dance at the same pace' in successful educational dialogs



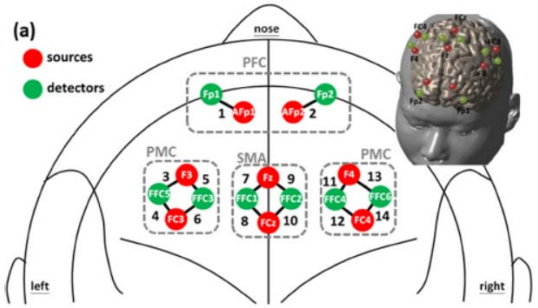

Battro, Antonio M., et al. *Mind, Brain, and Education* 7.3 (2013): 177-181.



# Dual Tasks

- In daily life, mobility requires walking while performing a cognitive or upper-extremity motor task.
- The theory of multiple resource models
  - The dual-task interference is minimal if 2 tasks use differing functional resources (Pashler H, 1994).
- The capacity-sharing theory & bottleneck theory
  - Performing 2 tasks with similar cognitive or motor demands can cause retardations in both tasks or delays in the secondary task (Ruthruff E, 2001; Tombu M, 2003).

# Experiment Setup





*NIRSport*

*GAITrite*

International 10-5 system setup covering bilateral prefrontal, premotor, and supplementary motor areas.

Lu, CF, et al. *PloS one* 10.6 (2015): e0129390.



# Gait Performance

| Gait data | NW | WCT | WMT | Statistical results | *p*-value* |
|---|---|---|---|---|---|
| Speed | 112.69±11.90 | 102.66±11.23 | 103.98±12.35 | NW > WCT | < 0.0001 |
| (cm/second) | | | | NW > WMT | 0.0033 |
| | | | | WCT = WMT | 0.5415 |
| Cadence | 114.56±6.22 | 110.19±6.51 | 115.70±6.25 | NW > WCT | < 0.0001 |
| (steps/min) | | | | NW = WMT | 0.3855 |
| | | | | WCT < WMT | < 0.0001 |
| Stride time | 1.06±0.06 | 1.09±0.06 | 1.04±0.05 | NW < WCT | 0.0040 |
| (second) | | | | NW = WMT | 0.2153 |
| | | | | WCT > WMT | < 0.0001 |
| Stride length | 118.58±10.72 | 112.28±10.49 | 108.45±11.10 | NW > WCT | < 0.0001 |
| (cm) | | | | NW > WMT | < 0.0001 |
| | | | | WCT = WMT | 0.0427 |
| Gait variability | 2.69±0.85 | 2.38±1.01 | 2.94±1.02 | NW = WCT | 0.3196 |
| (%) | | | | NW = WMT | 0.3525 |
| | | | | WCT = WMT | 0.1172 |

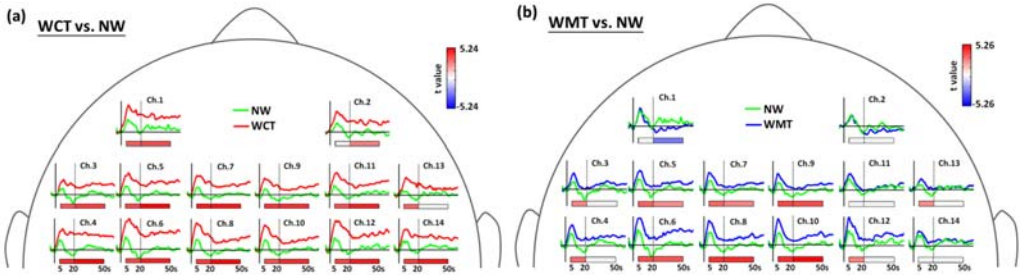
*The significance was defined as $p<0.016$ (Bonferroni correction for multiple testing).

Lu, CF, et al. *PloS one* 10.6 (2015): e0129390.



# Brain Activity

- Walking while cognitive tasking (WCT)
  - Walking on a walkway while serially subtracting 7 from an initial 3-digit number
- Walking while motor tasking (WMT)
  - Walking on the same walkway while carrying a 600-mL bottle of water on a tray.



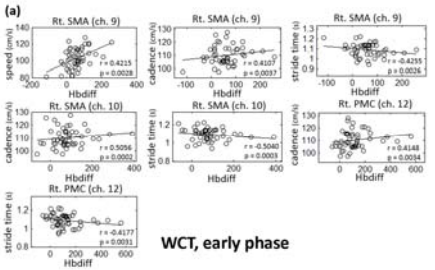

Lu, CF, et al. *PloS one* 10.6 (2015): e0129390.



# Maintaining Gait Performance by Cortical Activation during Dual-Task Interference

**Correlation Analysis in the Early Phase (5~20 s)**

| Walking condition | Brain area | Gait data | Correlation coefficient | *p*-value |
|---|---|---|---|---|
| WCT | Lt. SMA (ch.8) | cadence | 0.4117 | 0.0040 |
| | Lt. SMA (ch.8) | stride time | -0.4095 | 0.0043 |
| | Rt. SMA (ch.9) | speed | 0.4701 | 0.0008 |
| | Rt. SMA (ch.9) | cadence | 0.4299 | 0.0026 |
| | Rt. SMA (ch.9) | stride time | -0.4466 | 0.0017 |
| | Rt. SMA (ch.10) | cadence | 0.4579 | 0.0012 |
| | Rt. SMA (ch.10) | stride time | -0.4640 | 0.0004 |
| WMT | Lt. PMC (ch.3) | stride length | 0.4374 | 0.0019 |
| | Lt. PMC (ch.4) | speed | 0.5215 | 0.0001 |
| | Lt. PMC (ch.4) | stride length | 0.6010 | <0.0001 |
| | Lt. PMC (ch.5) | speed | 0.4839 | 0.0005 |
| | Lt. PMC (ch.5) | stride length | 0.5148 | 0.0002 |
| | Lt. PMC (ch.6) | stride length | 0.4681 | 0.0008 |
| | Rt. SMA (ch.10) | stride length | 0.4473 | 0.0014 |

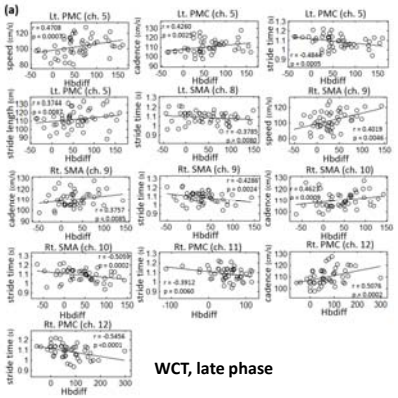



Lu, CF, et al. *PloS one* 10.6 (2015): e0129390.

## Maintaining Gait Performance by Cortical Activation during Dual-Task Interference

**Correlation Analysis in the Late Phase (20~50 s)**

| Walking condition | Brain area | Gait data | Correlation coefficient | *p*-value |
|---|---|---|---|---|
| WCT | Lt. PMC (ch.5) | speed | 0.4564 | 0.0013 |
| | Lt. PMC (ch.5) | cadence | 0.3937 | 0.0062 |
| | Lt. PMC (ch.5) | stride time | -0.4552 | 0.0013 |
| | Lt. SMA (ch.8) | cadence | 0.3817 | 0.0081 |
| | Lt. SMA (ch.8) | stride time | -0.4391 | 0.0020 |
| | Rt. SMA (ch.9) | speed | 0.4818 | 0.0006 |
| | Rt. SMA (ch.9) | cadence | 0.4128 | 0.0039 |
| | Rt. SMA (ch.9) | stride time | -0.4690 | 0.0009 |
| | Rt. SMA (ch.9) | stride length | 0.4308 | 0.0025 |
| | Rt. SMA (ch.10) | cadence | 0.4168 | 0.0036 |
| | Rt. SMA (ch.10) | stride time | -0.4665 | 0.0009 |
| | Rt. PMC (ch.11) | stride time | -0.3903 | 0.0067 |
| | Rt. PMC (ch.12) | cadence | 0.4710 | 0.0008 |
| | Rt. PMC (ch.12) | stride time | -0.5135 | 0.0002 |
| WMT | Lt. PMC (ch.4) | speed | 0.5377 | <0.0001 |
| | Lt. PMC (ch.4) | stride length | 0.4818 | 0.0005 |

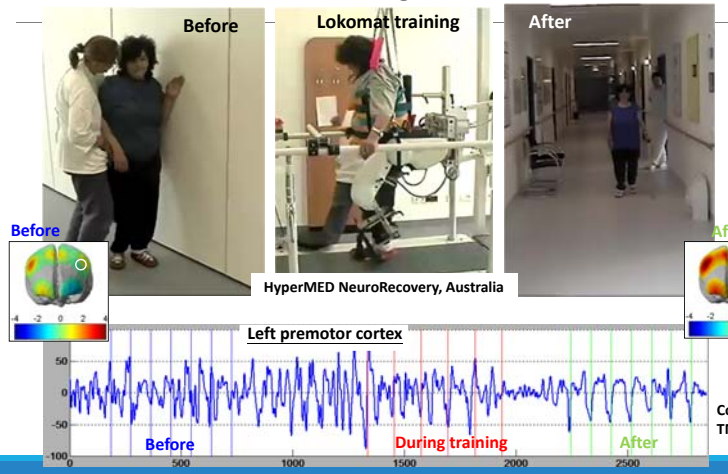


WCT, late phase

Lu, CF, et al. *PloS one* 10.6 (2015): e0129390.



## Neuroplasticity and Restoration of Motor Control Circuits after Stroke with Robot Training




Collaborate with Prof. Shih-Ching Chen, TMUH



## Generalized Anxiety Disorder

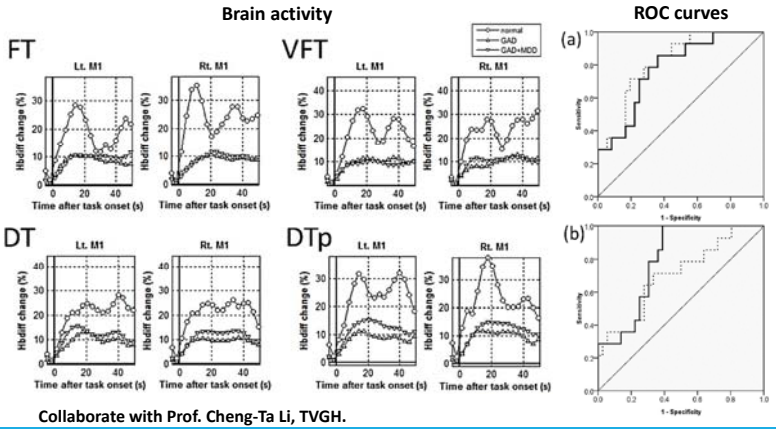
- A chronic and common mental disorder.
- **Excessive worries and muscle tension** have been reported as the most specific symptom associated with GAD.
- Worry has been found to significantly change activities of primary motor cortex (M1) and corticospinal motor responses to magnetic stimulation in M1 (Oathes DJ, 2008).

**M1 ➔ A reliable biomarker for GAD??**


**Collaborate with Prof. Cheng-Ta Li, TVGH.**



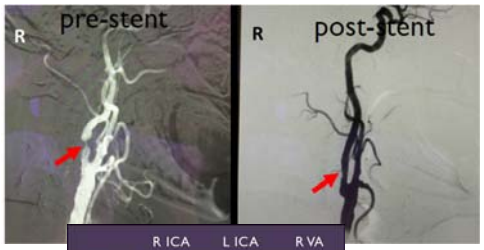
## M1 Activity as a GAD Biomarker



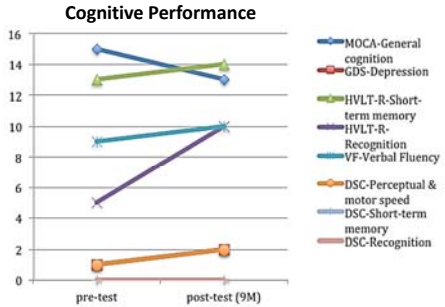

**Collaborate with Prof. Cheng-Ta Li, TVGH.**

# Therapeutic effect of ICA Stenting

- 80 year-old man
- Medical Hx: coronary artery disease, hypertension and type II diabetes mellitus.
- Reason of neurological referral: dizziness




| | R ICA | L ICA | R VA |
|---|---|---|---|
| PRE-STENT | 90% | 40% | hypoplasia |
| POST-STENT | 30% | 40% | hypoplasia |

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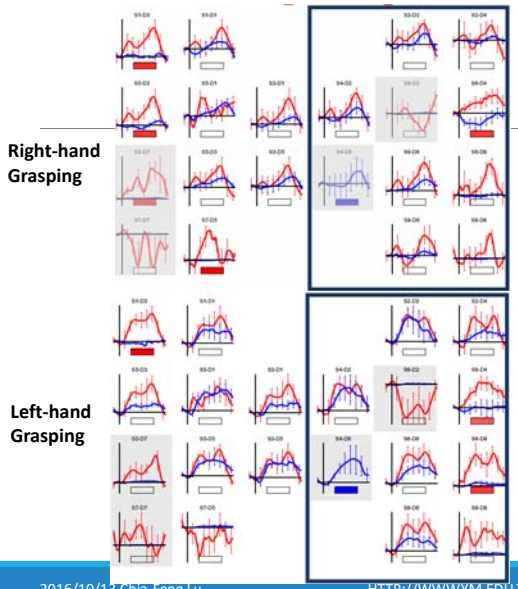
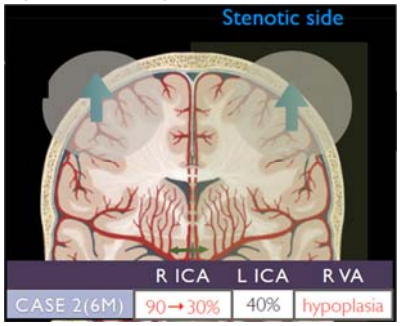



**MCA territory: Sensorimotor area**

**post-stent**

**pre-stent**

**Improved hemodynamic after carotid stenting.**




**Collaborate with Prof. Chang-Ming Chern, TVGH.**



# Summary & Perspectives

- Wearable, natural, and unrestrained setup
  - Neurorehabilitation
  - Sport medicines
  - Social interaction (hyperscanning)
  - Complex teaching & learning approach
- Beyond brain hemodynamics
  - Oscillatory neural activity (> 4 Hz)
  - Neural membrane potential (>50 Hz)

**Human interaction & complex study model design!**



# THE END

Thanks for your attention : )

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