

近紅外光量測與功能性磁振造影

fNIRS and functional MRI

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2015/3/26 Lesson 5, Chia-Feng Lu

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本週課程內容

- Physiology of neural activity
- Comparisons of fNIRS and fMRI

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神經活化生理機轉

Physiology of neural activity

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Aspects of Neural Activity

- Synaptic transmission
 - Local field potential (LFP)
 - Input to the neuron
- Action potentials (spikes)
 - Output signals
 - Permit communications between neurons

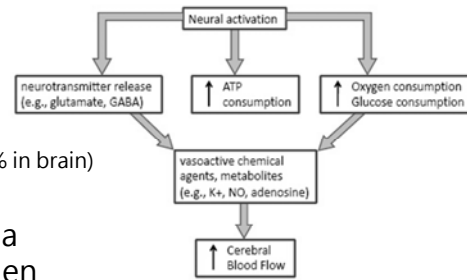
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Neurovascular Coupling

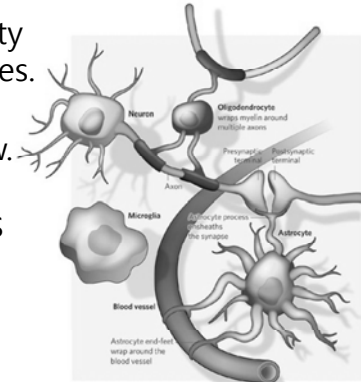
- ATP is essential for neural activity
 - Restoration of ionic gradients
 - neurotransmitter recycling
- Glycolysis
 - a small amount of ATP
- Oxidative glucose metabolism (90% in brain)
 - a large amount of ATP
- Cerebral metabolism depends on a constant supply glucose and oxygen



Neurovascular coupling, scholarpedia.

Neurovascular Coupling

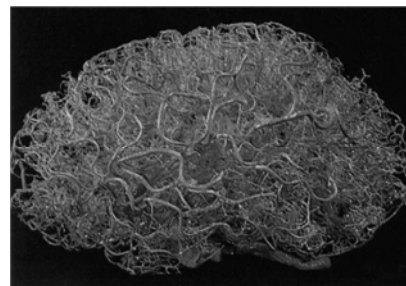
- Multiple mechanisms...
 - Astrocytes links neurotransmitter activity (glutamate cycling) to vascular responses.
 - Direct neuronal innervation of smooth muscle cells can also control blood flow.
- Requirement of metabolic nutrients
- Elimination of waste products
 - CO₂ and excessive heat



Neurovascular Coupling

- A continuous supply of energy substrates is maintained by CBF
- Neural activity
 - Blood perfusion via capillaries ↑
 - regional cerebral blood flow (rCBF) ↑
 - regional cerebral blood oxygenation (rCBO) ↑
- Changes in rCBF or rCBO can be used to map brain activity
 - Functional neuroimaging

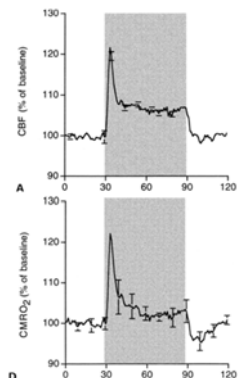
Brain vascular system: glucose and oxygen



Zlokovic & Apuzzo, 1998.

CBF and O₂ Consumption Mismatch

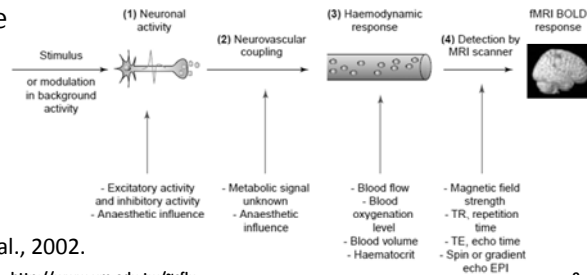
- During neural activity...
 - The fractional increases in CBF and glucose consumption are similar in magnitude.
 - Oxygen consumption increases much less than CBF.
- → A net increase of oxygen in the blood and tissue.



CMRO₂: cerebral metabolic rate of oxygen
Ances et al., JCBFM 2001.

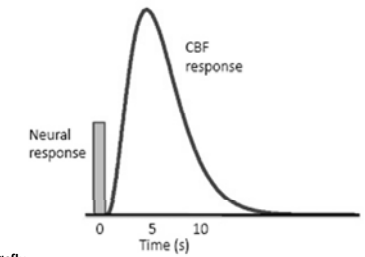
BOLD fMRI

- Blood-oxygenation level dependent (BOLD)
- BOLD fMRI detects the alterations in
 - The level of deoxygenated hemoglobin
 - Cerebral blood volume



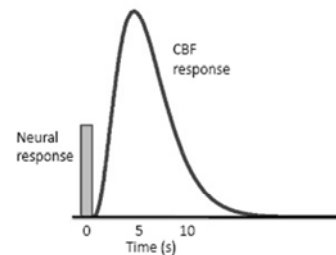
Coupling Properties

- Use of vascular responses to infer neural activity
 - Time: lack of temporal information in vascular response
 - Space: focal activation of neurons \leftrightarrow local vascular response?
 - Amplitude: linear relationship?



Coupling Properties: Time

- CBF vs. neural activation
 - Delayed by 1 ~ 2 s
 - Peaks 4 ~ 6 s after the neural response
- Fast modulation of neural activity is unlikely to be reflected in the vascular response.



- slow reaction of smooth muscle cells
- slow diffusion and uptake of neurovascular mediators

Coupling Properties: Space

- Spatial resolution of the vascular response
- Vascular point spread function (PSF)
 - 1~5 mm
 - Depends on imaging conditions: monitoring tech., magnetic field, pulse sequence, species, and brain regions.
- Gray matter,
 - densest network of capillaries, intervessel distance of $\sim 25 \mu\text{m}$

Coupling Properties: Amplitude

- In general, amplitude coupling appears to be largely linear.
 - For stimulus durations larger than 4 s
- Various nonlinearities have been noted
 - neural responses below a certain amplitude may not evoke a CBF response
 - neural responses may saturate, while vascular responses continue to increase

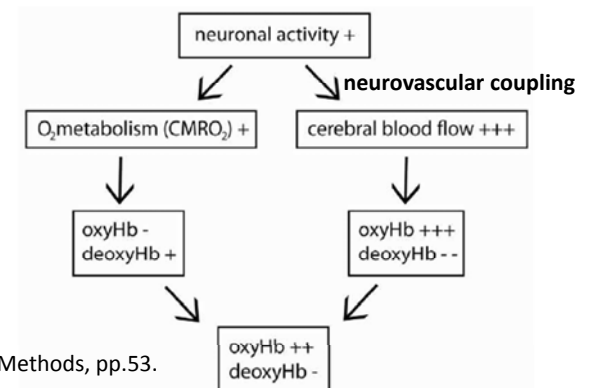
Alteration Factors

- Disease
 - the chemical mediators
 - the dynamics of the vascular system
 - hypertension, diabetes, and AD alter Ionic channels on vascular smooth muscle
- Aging
 - change the vascular system
 - increasing tortuosity or reducing elasticity of the blood vessels
- Pharmacology
 - Diazoxide is used as a vasodilator → large vascular responses with little or no change in neural activity.
 - Hypercapnia (the concentration of CO₂ in the blood ↑) → vasodilation.

fNIRS與fMRI比較 Comparisons of fNIRS and fMRI

Metabolic and hemodynamic changes

- Mismatch between CBF and O₂ consumption
- Brain activation
 - Elevated oxy-Hb
 - Decrease deoxy-Hb



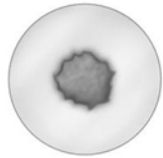
Neuroimaging – Methods, pp.53.

Hemoglobin



Oxygenated Hemoglobin

- Diamagnetic
- Doesn't distort surrounding magnetic field
- No signal loss in BOLD signal



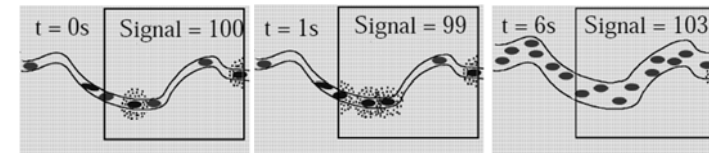
Deoxygenated Hemoglobin

- Paramagnetic
- Distorts surrounding magnetic field
- Signal loss in BOLD signal !!!

fMRI slides from <http://culhamlab.ssc.uwo.ca/fmri4newbies/Tutorials.html>

fMRI BOLD signal

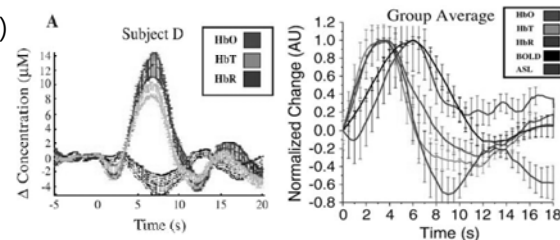
- $t = 0s$, a steady state in which there is a given amount of oxygenated and deoxygenated hemoglobin.
- $t = 1s$, an increased of deoxygenated hemoglobin due to the oxygen demands of neuronal activation.
- $t = 6s$, an increased of blood supply and oxygenated hemoglobin "flush away" the deoxygenated ones.



Matthijs Vink, 2007.

Hemoglobin and BOLD

- The deoxy-Hb in concentration is the major factor determining the time course of the BOLD signal.
- Correlations with BOLD
 - deoxy-Hb ($R=0.98, P < 10^{-20}$)
 - oxy-Hb ($R=0.71$)
 - total Hb ($R=0.53$)
- Correlations with CBF
 - total Hb ($R=0.91, P < 10^{-10}$)
 - oxy-Hb ($R=0.83, P < 10^{-5}$)

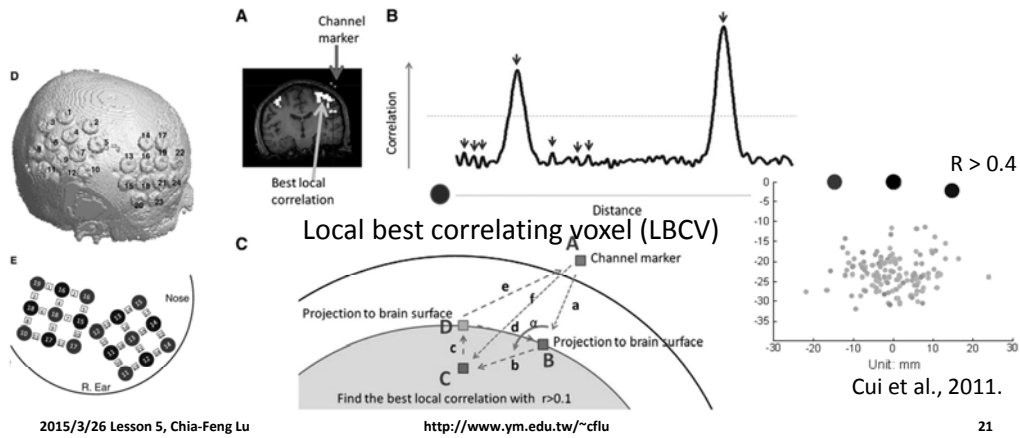


Huppert et al., 2006.

Quatitative Comparisons

- Simultaneous fNIRS and fMRI measurements in
 - Motor task
 - Working memory task
 - Multiple cognitive task
 - Visual stimulus
- Coverage
 - Frontal/prefrontal cortex
 - Sensorimotor cortex
 - Parietal cortex
 - Visual cortex

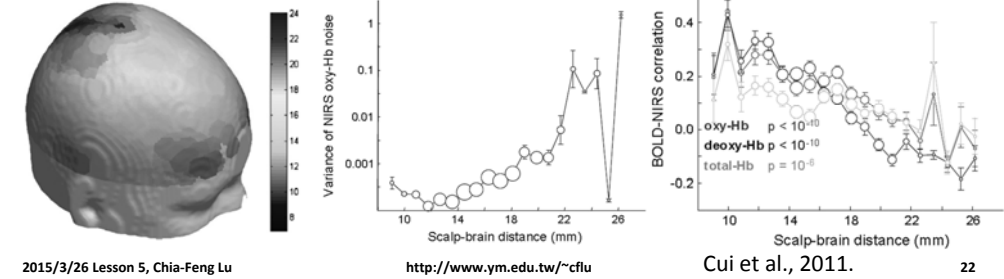
Spatial Localization of fNIRS



Scalp-Brain Distance

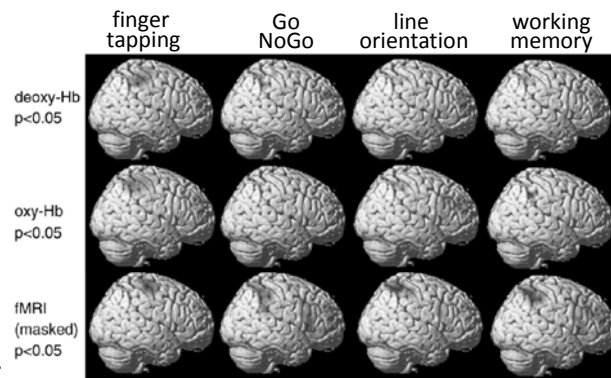
- A standard brain (colin27).
- Smaller distance in frontal regions and larger in parietal regions.
- Larger distances → lower BOLD-NIRS correlations

Mean distance is 16.8 mm



Activation maps

- Defined by GLM
- Similar patterns between NIRS and fMRI
- Less inferior resolution in the NIRS data



Resting state network

- Covering the frontal, temporal, and occipital cortices
- Highly correlate voxels (HCV) mainly distribute in brain tissue

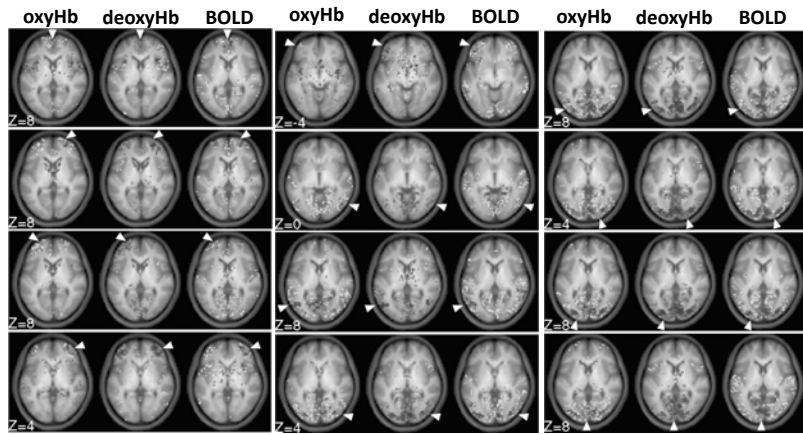


Distributions of HCVs with NIRS signals

Ch	Anatomical location of channel	oxy-Hb brain tissue (%)	Skull (%)	Skin (%)	r value of 100th ranked voxel	deoxy-Hb brain tissue (%)	Skull (%)	Skin (%)	r value of 100th ranked voxel
1	Frontal_Sup_Medial_L	92	6	2	0.33	89	8	3	-0.30
2	Frontal_Sup_R	95	3	2	0.41	93	4	3	-0.37
3	Frontal_Sup_L	93	4	3	0.40	94	4	2	-0.40
4	Frontal_Mid_R	85	5	10	0.32	81	7	12	-0.31
5	Frontal_Mid_Corb_L	70	9	21	0.29	72	8	20	-0.32
6	Frontal_Inf_Tot_R	51	10	39	0.25	55	10	35	-0.24
7	Frontal_Inf_Corb_L	37	9	54	0.25	51	8	41	-0.26
8	Temporal_Mid_R	94	3	3	0.41	90	5	5	-0.34
9	Temporal_Mid_L	91	5	4	0.36	85	7	8	-0.31
10	Occipital_Mid_Ant_L	95	2	3	0.49	88	5	7	-0.41
11	Occipital_Mid_Ant_L	94	4	2	0.45	85	8	7	-0.36
12	Occipital_Sup_R	96	2	2	0.54	88	6	6	-0.47
13	Occipital_Mid_Post_L	94	4	2	0.50	89	6	5	-0.44
14	Calcarine_L	92	5	3	0.46	81	10	9	-0.35

Sasai et al., 2012.

Resting state network



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Sasai et al., 2012.

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THE END
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