NIRS and fNIRS in clinical settings and clinical research

What expectations ?

Pr V Gremeaux
Dr D Laroche

Pôle Rééducation – Réadaptation CHU Dijon
Plateforme d'Investigation Technologique INSERM CIC 1432
INSERM U 1093 « Cognition, Action, et Plasticité Sensorimotrice »

Many fields!

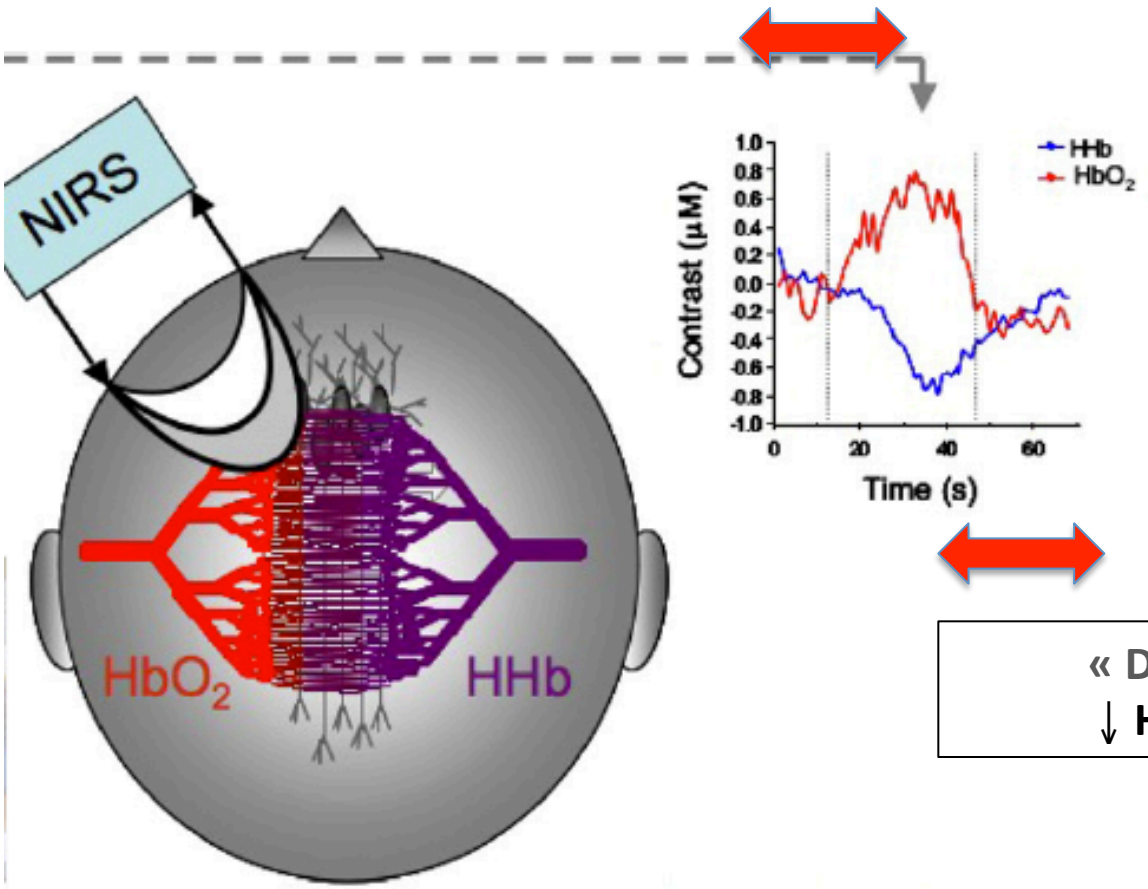
- **Cerebral applications**
  - Screening for subttle cognitive impairments
  - Assessing double tasks ability and attentionnal state
  - Understanding brain – muscle « dialogue »
    - Central part of exercise intolerance
    - positive effects of exercise on cognitive functions
    - Interaction physical – mental fatigue
    - Identifying neuroplasticity induced by rehabilitation

- **Muscular and vascular applications**
  - Assessing microcirculation disorders in patients with Cvasc risk factors
  - Assessing muscle metabolism
    - Determining ventilatory treshold
    - Improvements after an exercise training program
    - During eccentric exercise → improving its prescription
  - Assessing prognosis in amputees

Are all these expectations achievable?

NIRS at the brain level

Activation
Hb02 ↑ / HHb ↓ or =



« Deactivation »
↓ Hb02 / ↑ HHb

➡ Neurovascular coupling (brain activity) ➡ Haemodynamic **response**

Ekkekakis P, J Sports Ex Psychol 2009

1 - Early screening for subttle cognitive impairments ?

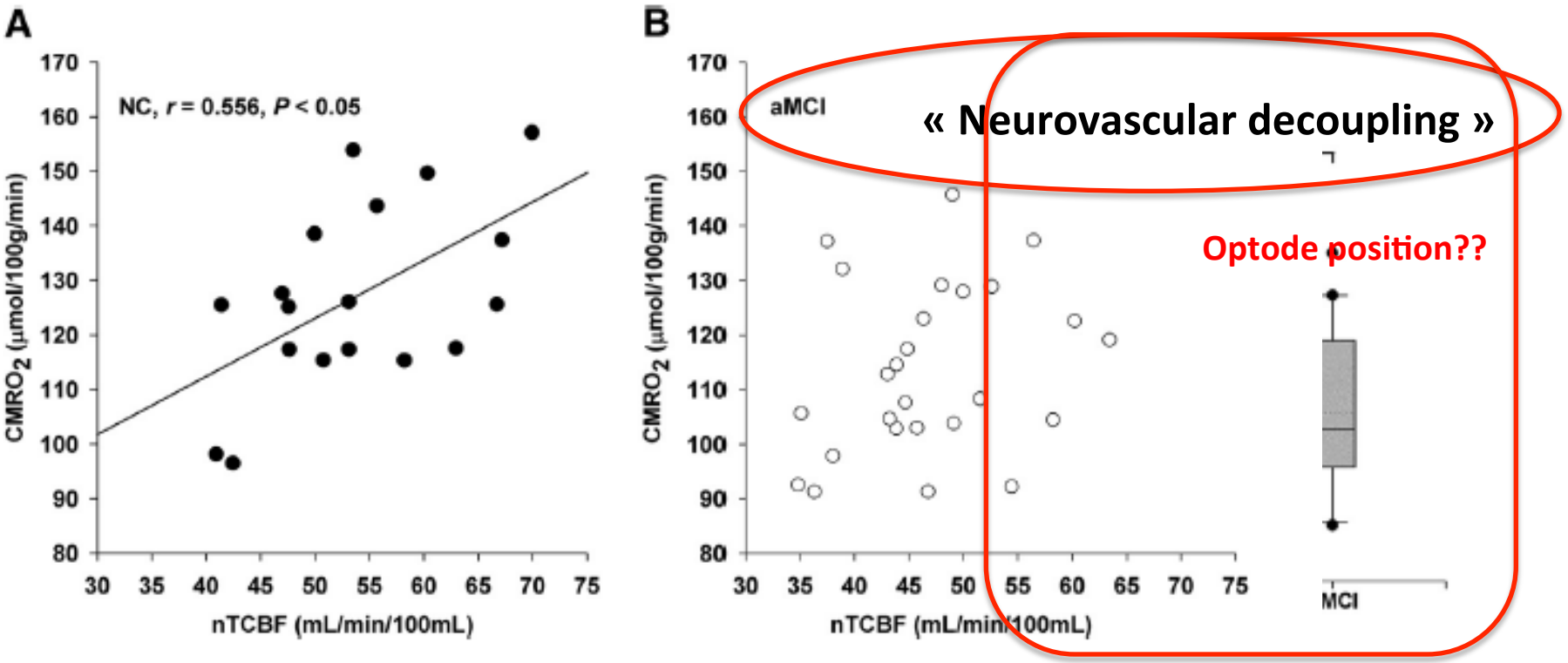
- At rest
- During cognitive tasks
- In ecological conditions

Global brain hypoperfusion and oxygenation in amnestic mild cognitive impairment

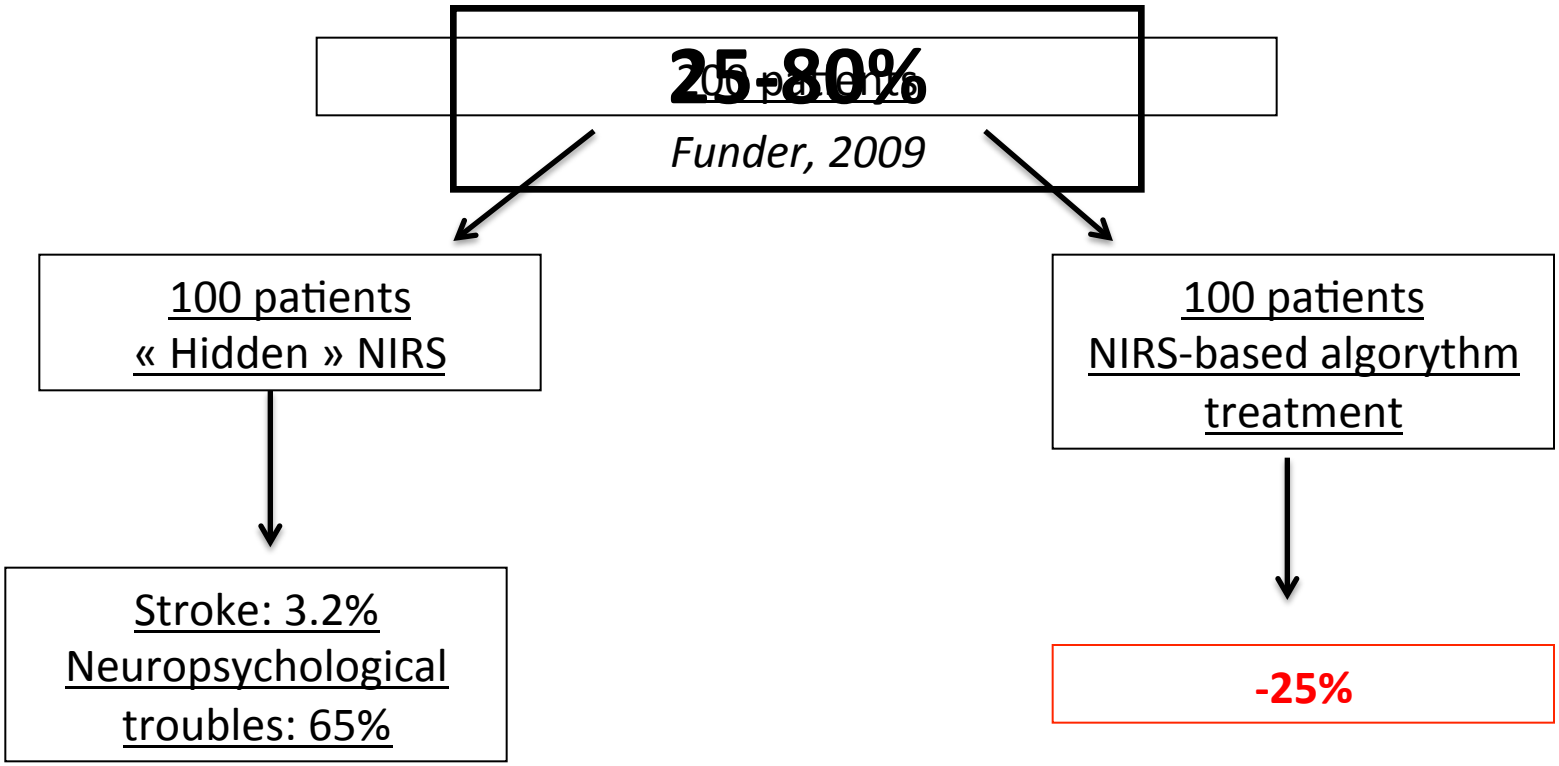
Jie Liu[a,b,g], Yong-Sheng Zhu[a,b], Muhammad Ayaz Khan[a,b], Estee Brunk[a], Kristin Martin-Cook[c], Myron F. Weiner[c,d], C. Munro Cullum[c,d], Hanzhang Lu[f], Benjamin D. Levine[a,b], Ramon Diaz-Arrastia[e], Rong Zhang[a,b,c,*]

Alzheimer's & Dementia

- Color-coded duplex ultrasonography: Total Cerebral Blood flow
- Spatially resolved NIRS: TOI (O2Hb/tHb) + CMRO2 calculation



A tool to decrease post-operative neurological and cognitive troubles during coronary artery bypass with extracorporeal circulation?



Murkin, Anesth Aanalg 2007

1 - Early screening for subttle cognitive impairments ?

- At rest
- During cognitive tasks :

  understanding (and preventing?) age-related cognitive decline

- In ecological conditions

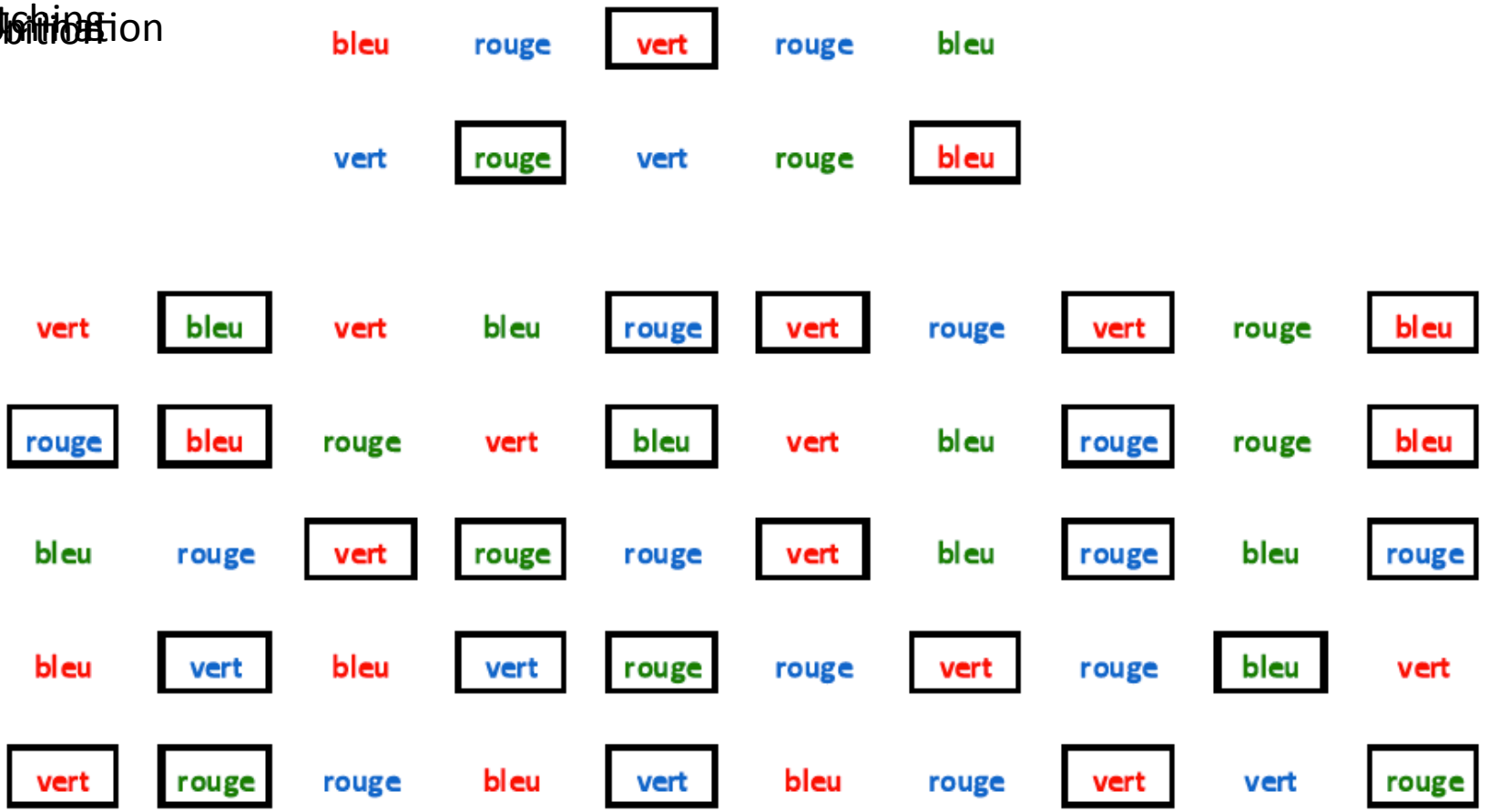
A fNIRS investigation of switching and inhibition during the modified Stroop task in younger and older adults

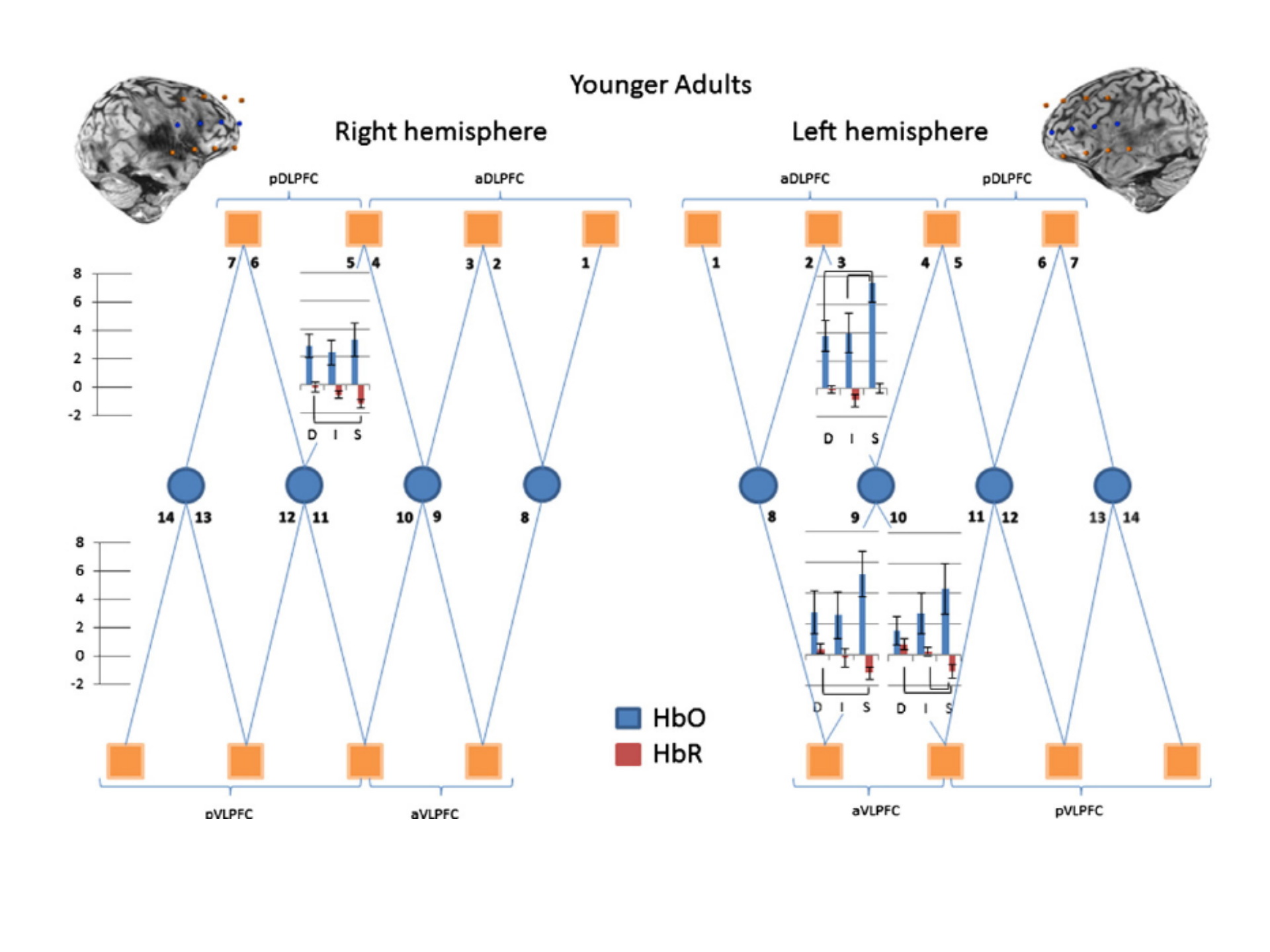
NeuroImage 64 (2013) 485–495

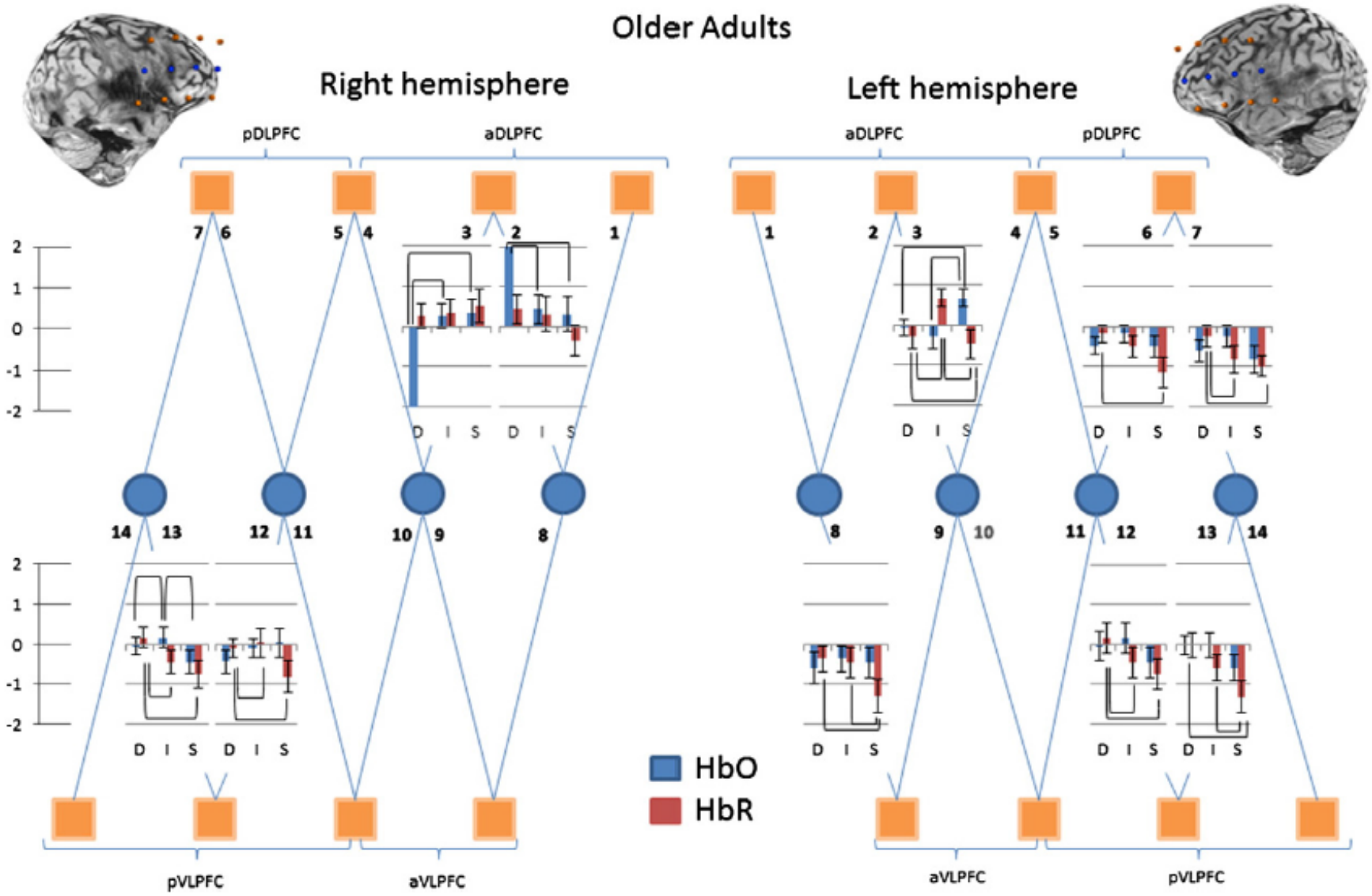
Maude Laguë-Beauvais [a,b], Julie Brunet [b,c], Louis Gagnon [d], Frédéric Lesage [e], Louis Bherer [a,b,*]

Switching

Inhibition




Younger Adults
Right hemisphere
Left hemisphere
pDLPFC
aDLPFC
aDLPFC
pDLPFC
7 6 5 4 3 2 1
1 2 3 4 5 6 7
8 6 4 2 0 -2
D I S
14 13 12 11 10 9 8
8 9 10 11 12 13 14
HbO
HbR
pVLPFC
aVLPFC
aVLPFC
pVLPFC


Older Adults
Right hemisphere
Left hemisphere
pDLPFC
aDLPFC
aDLPFC
pDLPFC
7 6 5 4 3 2 1
1 2 3 4 5 6 7
2
1
0
-1
-2
D I S D I S
14 13 12 11 10 9 8
8 9 10 11 12 13 14
HbO
HbR
pVLPFC
aVLPFC
aVLPFC
pVLPFC

- Inhibition and switching are associated with different patterns of pre-frontal activation

- Age-related difference in these patterns: prefrontal activation more spread out in older

→ **Multimodal cognitive stimulation++**

1 - Early screening for subttle cognitive impairments ?

- At rest
- During cognitive tasks
- In more ecological conditions : double task

Perspectives

Clinical Interventions in Aging

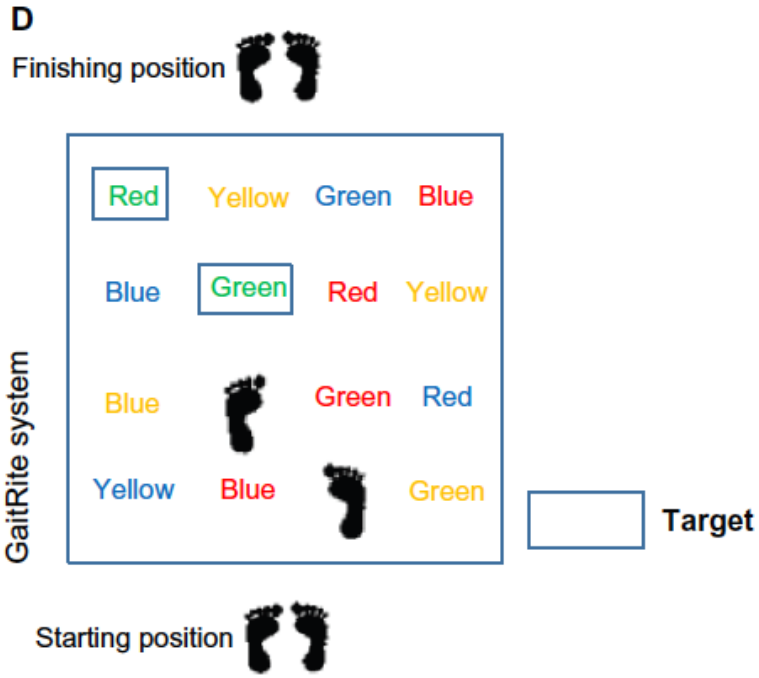
Dovepress
open access to scientific and medical research

Open Access Full Text Article

ORIGINAL RESEARCH

Walking Stroop carpet: an innovative dual-task concept for detecting cognitive impairment

A Perrochon[1,2,5]
G Kemoun[1,2]
E Watelain[3,4]
A Berthoz[5]



+

Conclusion: The Walking Stroop carpet is a dual-task test that enables early detection of cognitive fragility that has not been revealed by traditional neuropsychological tests or single-task walking analysis.

2 – Assessing double task ability

2 – Assessing double task ability

Low exercise capacity in elderlies, chronic heart failure, chronic diseases…

→ **risk of falls**

Decline in executive control during acute bouts of exercise as a function of exercise intensity and fitness level

Brain and Cognition 81 (2013) 10–17

Véronique Labelle [a,b], Laurent Bosquet [c,d,1], Saïd Mekary [b,c], Louis Bherer [a,b,*]

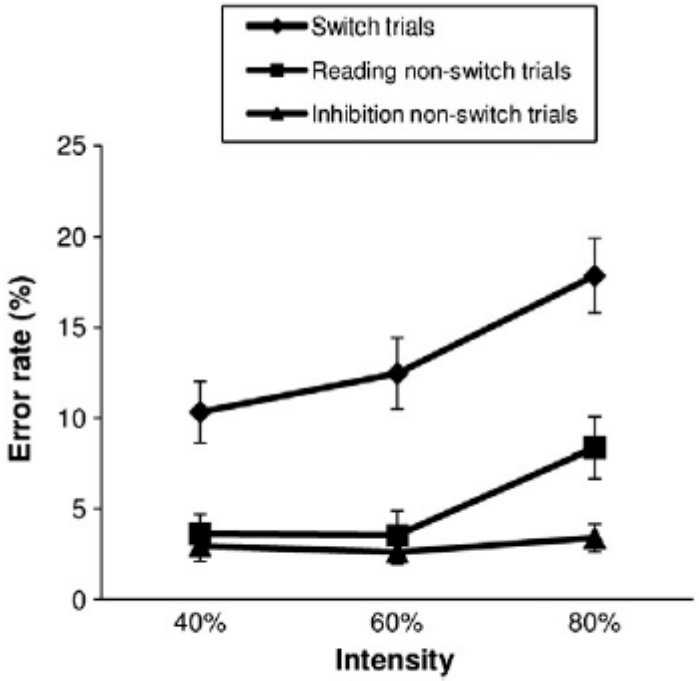


Fig. 1. Mean error rate as a function of exercise intensity in the switching, reading non-switch trials and inhibition non-switch trials of the switching condition.

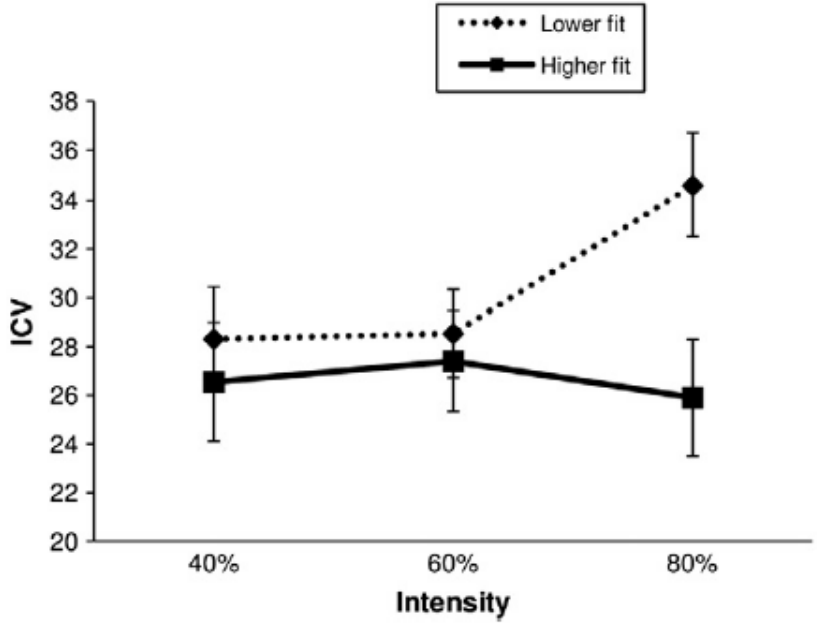
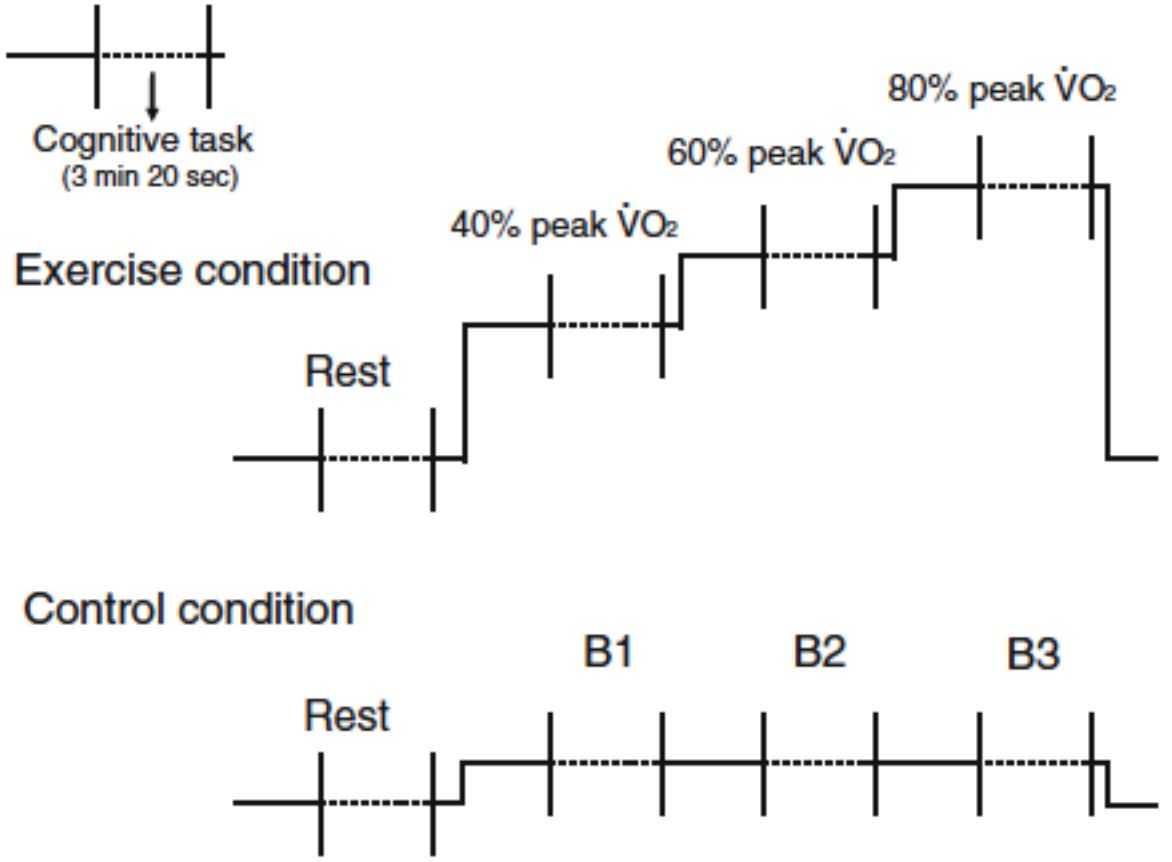


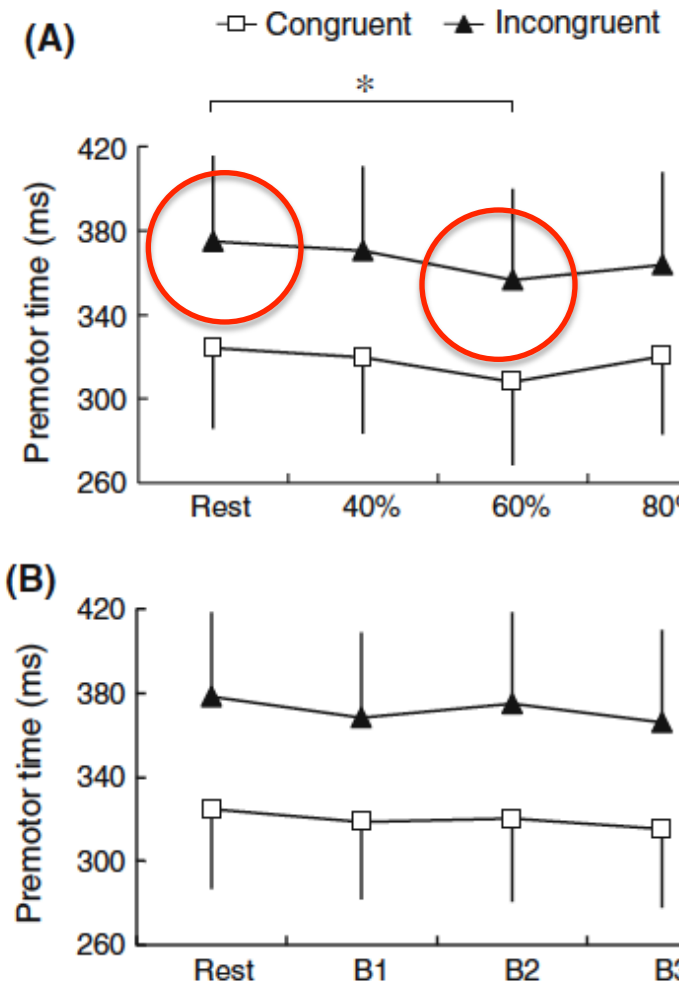
Fig. 2. Mean coefficient of variability (ICV) in the inhibition non-switch trials of the switching condition as a function of exercise intensity in lower and higher fit participants.

Does cerebral oxygenation affect cognitive function during exercise?

Eur J Appl Physiol (2011) 111:1973–1982

Soichi Ando · Masahiro Kokubu · Yosuke Yamada · Misaka Kimura





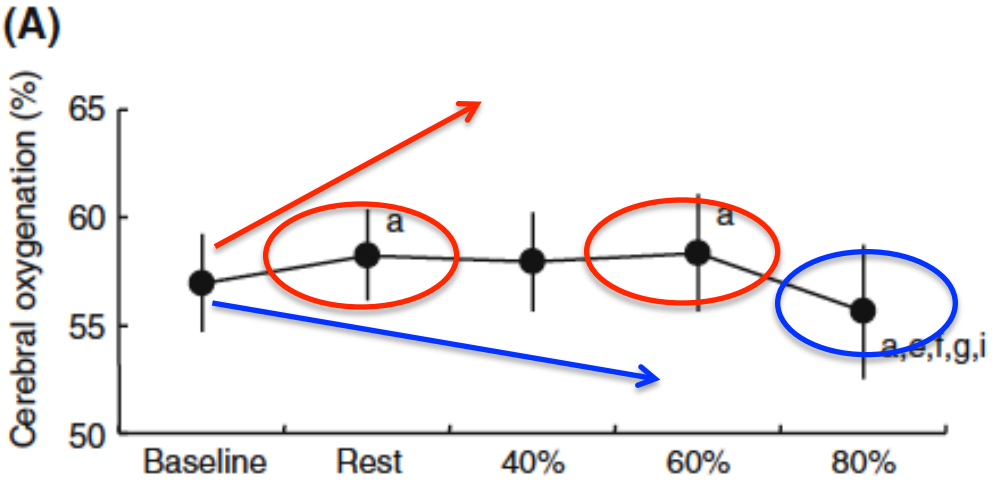


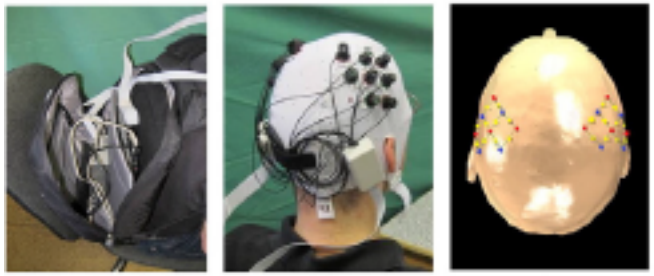
Fig. 2 The premotor time in the exercise (a) and control
tions. *Filled triangles* represent incongruent trials. *Ope*

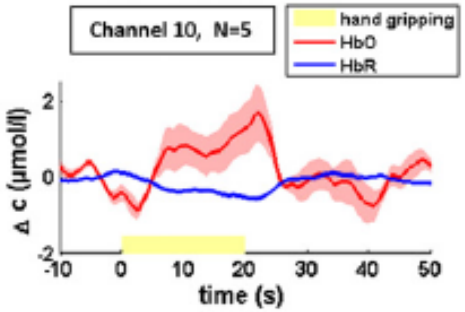
A wearable multi-channel fNIRS system for brain imaging in freely moving subjects

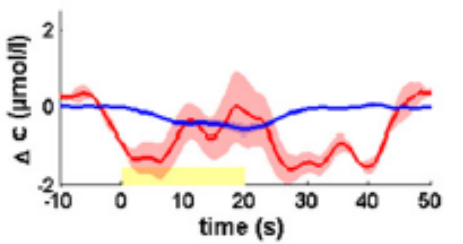
NeuroImage 85 (2014) 64–71

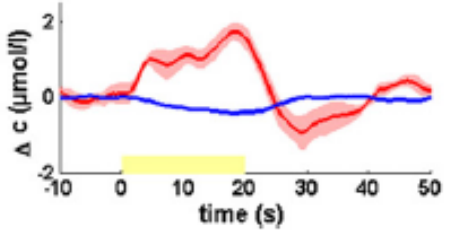
Sophie K. Piper [a,*], Arne Krueger [a], Stefan P. Koch [a], Jan Mehnert [a,b], Christina Habermehl [a], Jens Steinbrink [a,b], Hellmuth Obrig [c,d], Christoph H. Schmitz [a,e,1]

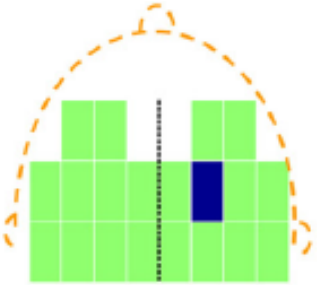
- 8 Subjects: left Hangrip while
  - Cycling outdoor
  - Cycling indoor
  - Sitting

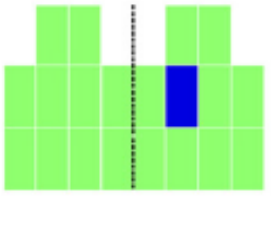


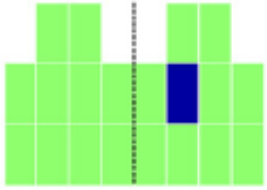


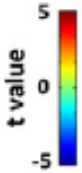


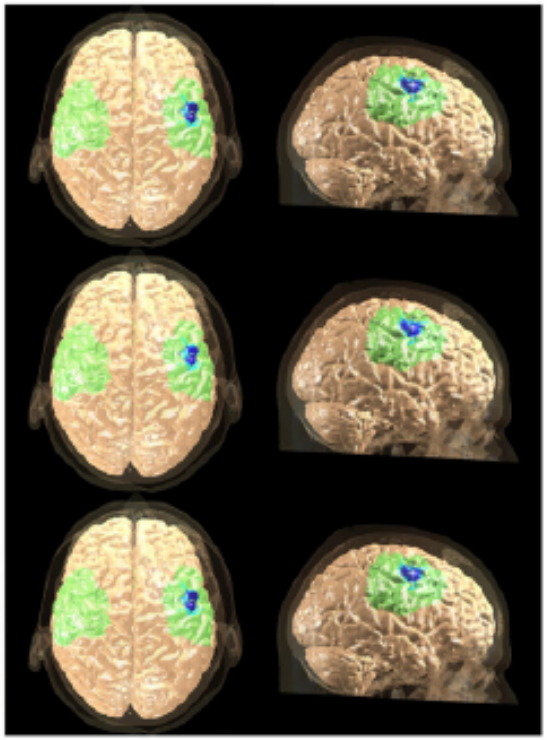












Perspectives

« Stop talking when walking » test

+

Perspectives

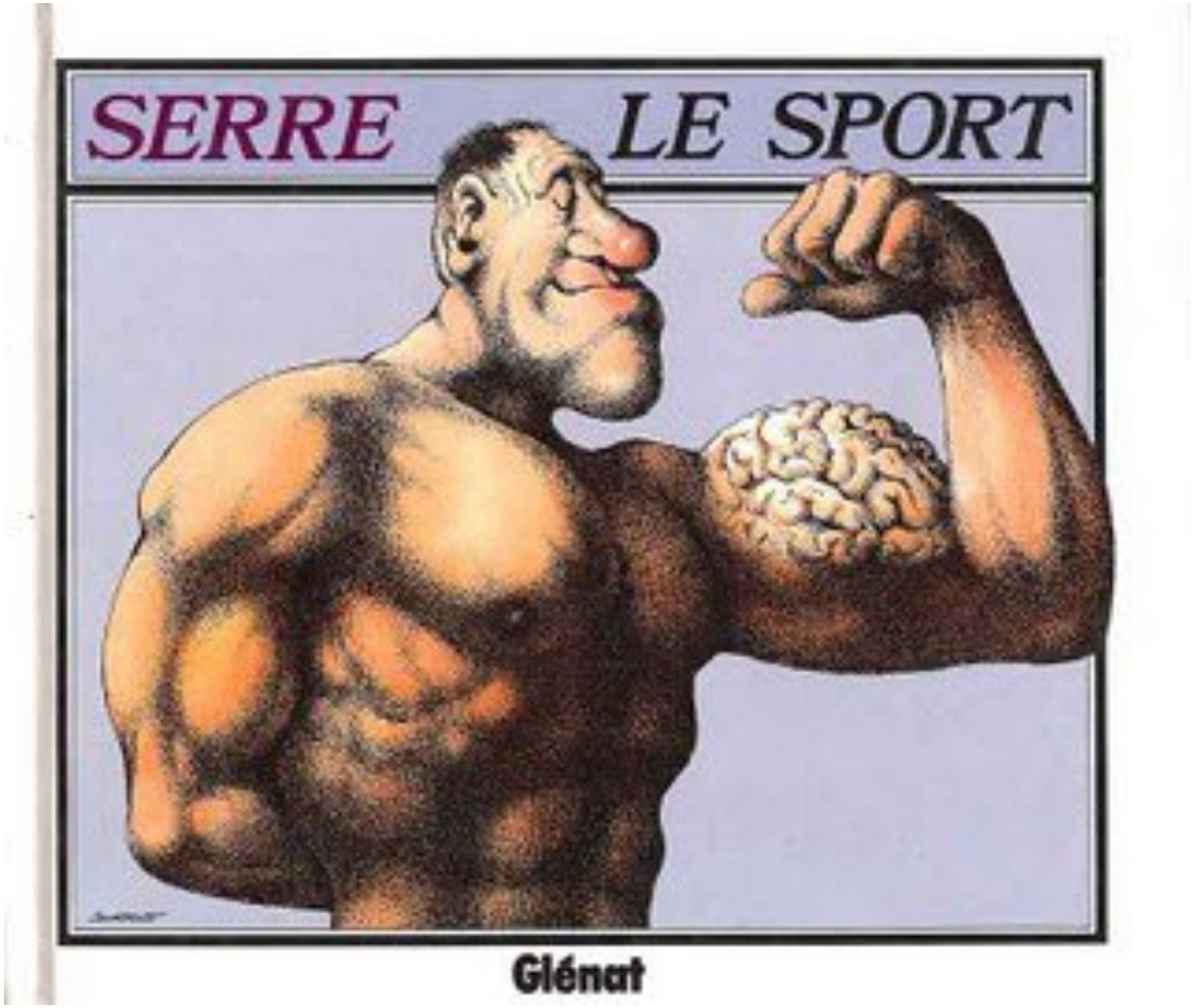
OPEN ACCESS Freely available online

PLOS | ONE

Towards a Near Infrared Spectroscopy-Based Estimation of Operator Attentional State

Gérard Derosière[1,2*], Sami Dalhoumi[2,3], Stéphane Perrey[1], Gérard Dray[3], Tomas Ward[2]

3- Understanding brain-muscle dialogue

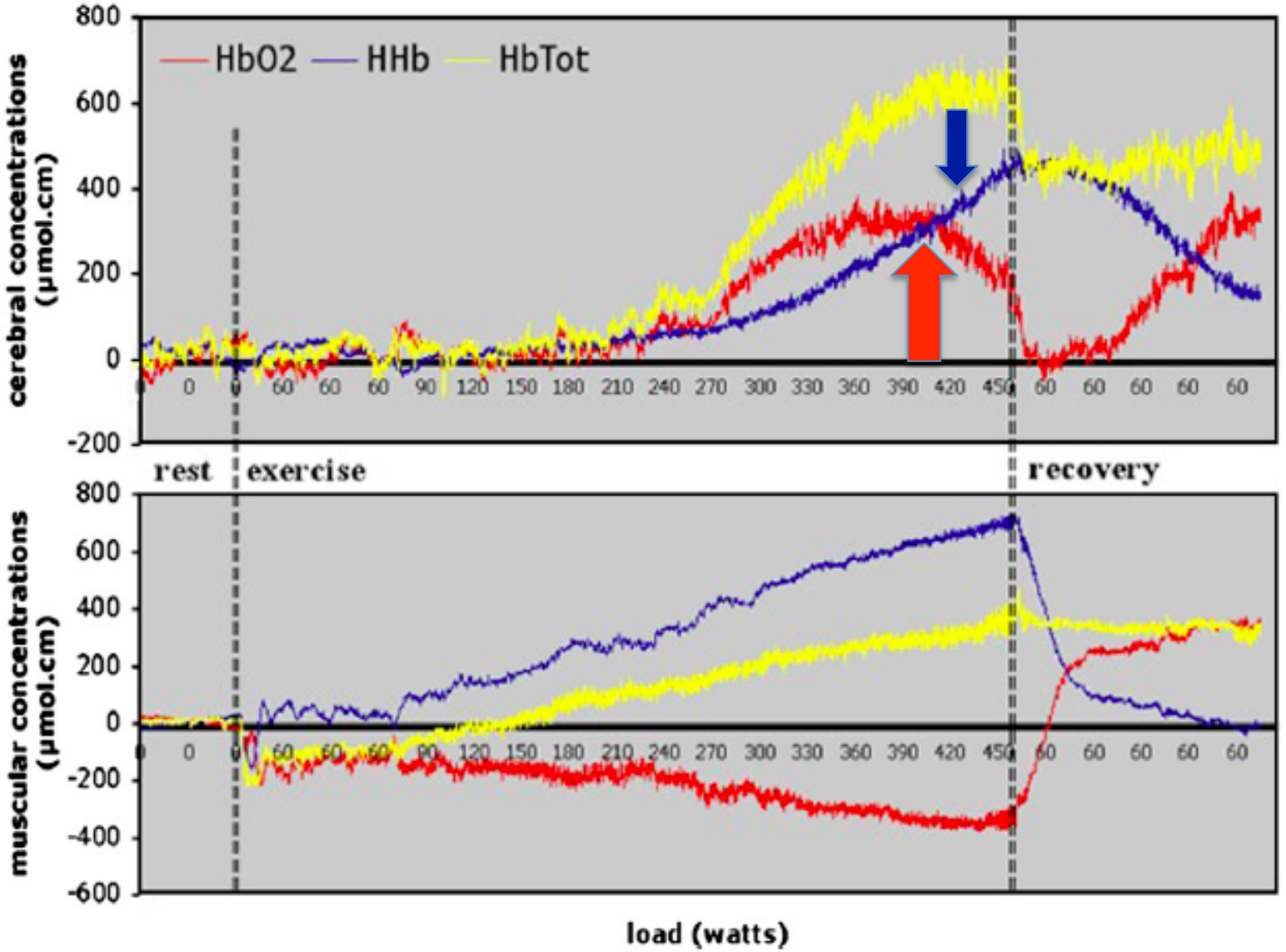


3- Understanding brain-muscle dialogue

- Central part of exercise intolerance
- Positive effects of exercise on cognitive functions
- Interaction physical – mental fatigue
- Identifying neuroplasticity induced by rehabilitation

Non-invasive NIR spectroscopy of human brain function during exercise

Stéphane Perrey* Methods 45 (2008) 289–299



Effects of incremental exercise on cerebral oxygenation measured by near-infrared spectroscopy: A systematic review

Cherie R. Rooks, Nathaniel J. Thom, Kevin K. McCully, Rod K. Dishman*

Department of Kinesiology, University of Georgia, 330 River Road, Athens, GA 30602-6554, United States

Progress in Neurobiology 92 (2010) 134–150

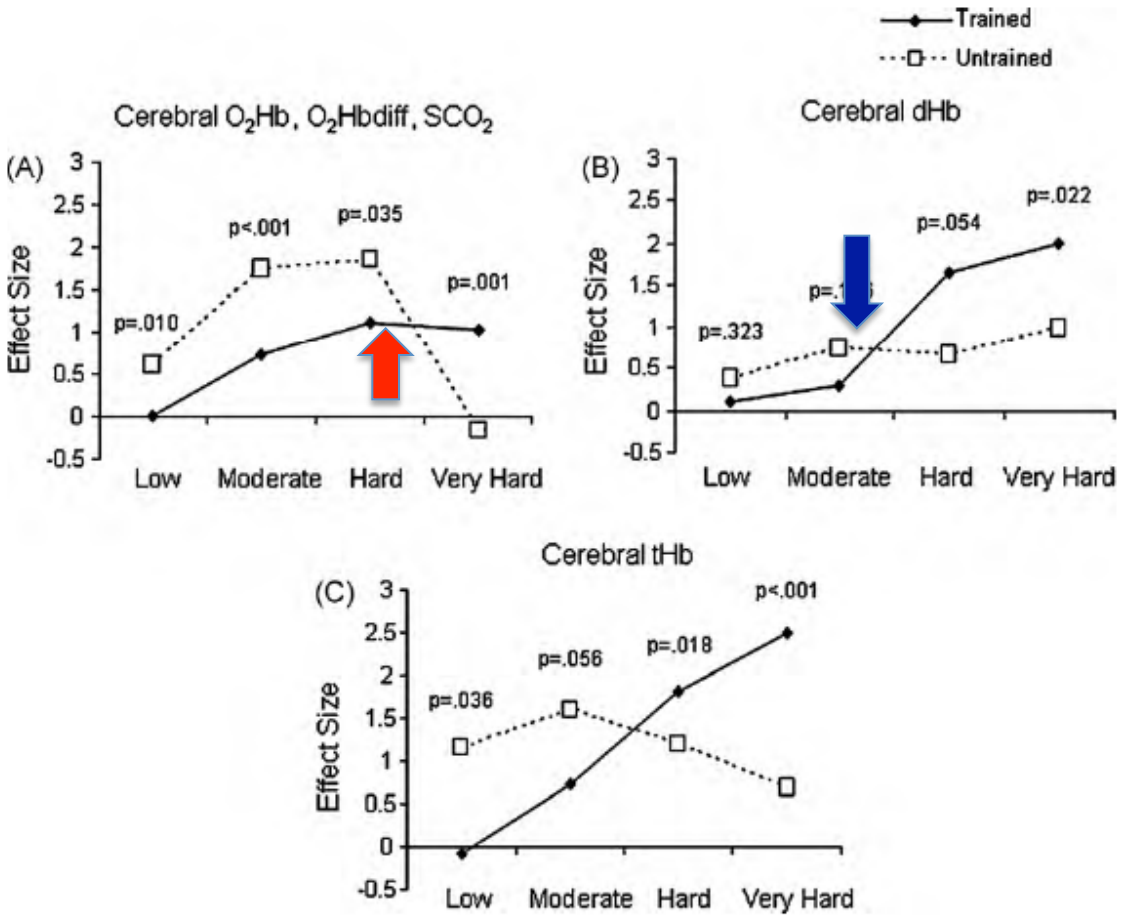


Fig. 5. Effects of exercise on (A) cerebral O_2Hb, $O_2Hbdiff$, SCO_2, (B) dHb, and (C) blood volume (tHb) at low, moderate, hard, and very hard intensities in aerobically trained and untrained individuals.

3- Understanding brain-muscle dialogue

- Central part of exercise intolerance
- Positive effects of fitness/exercise on cognitive functions
- Interaction physical – mental fatigue
- Identifying neuroplasticity induced by rehabilitation

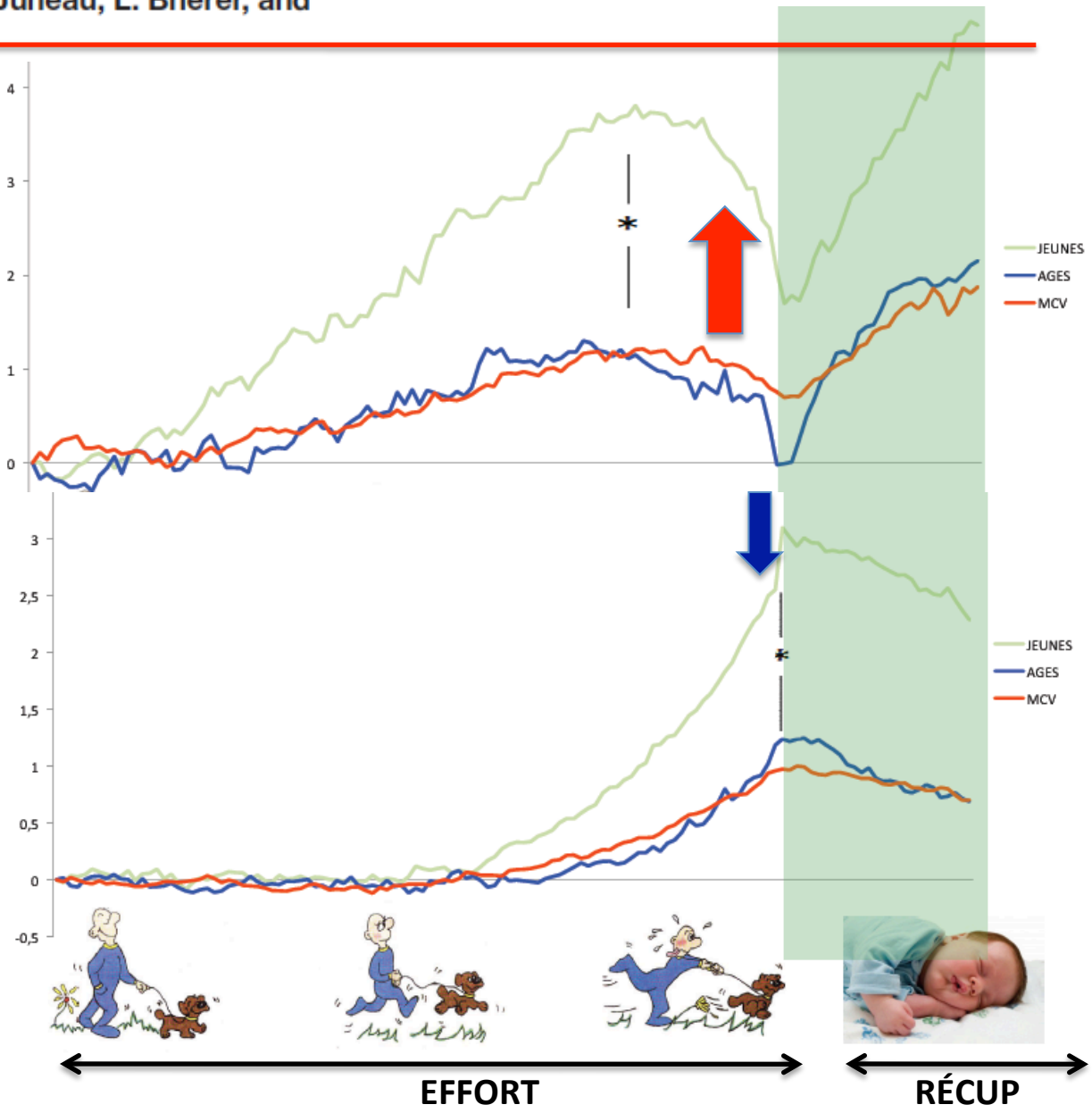
Cerebral oxygenation, exercise capacity, cardiac output, and cognitive performance in patients with coronary heart disease

M. Gayda, V. Gremeaux, J. Drigny, M. Juneau, L. Bherer, and A. Nigam

Appl. Physiol. Nutr. Metab. Vol. 36, 2011

O2Hb

HHb

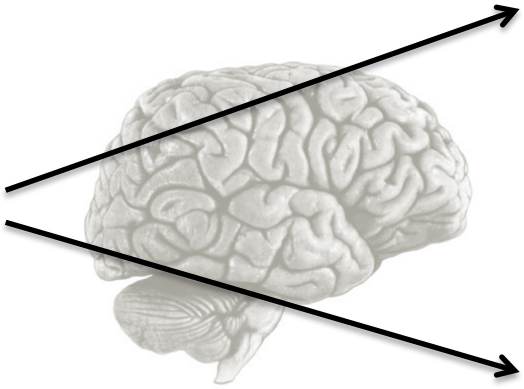


Left PFC NIRS during incremental exercise

Cognitive performance at rest and Left PFC NIRS during exercise in coronary artery disease patients

21 CAD patients

TMTB Percentile

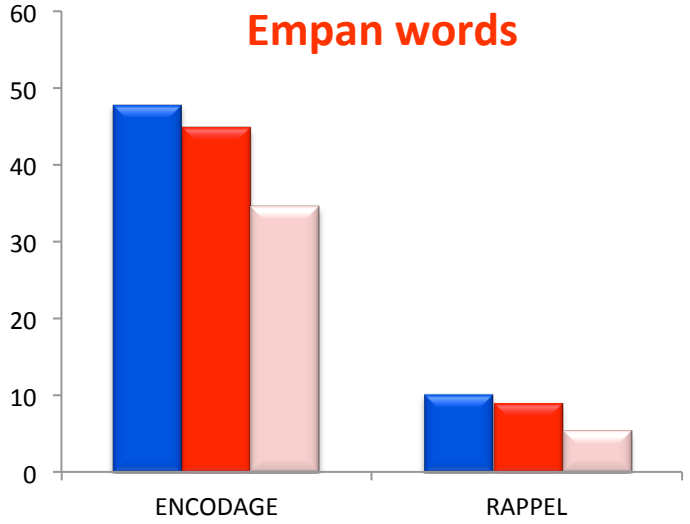


<50e = 12. (69,8 years)

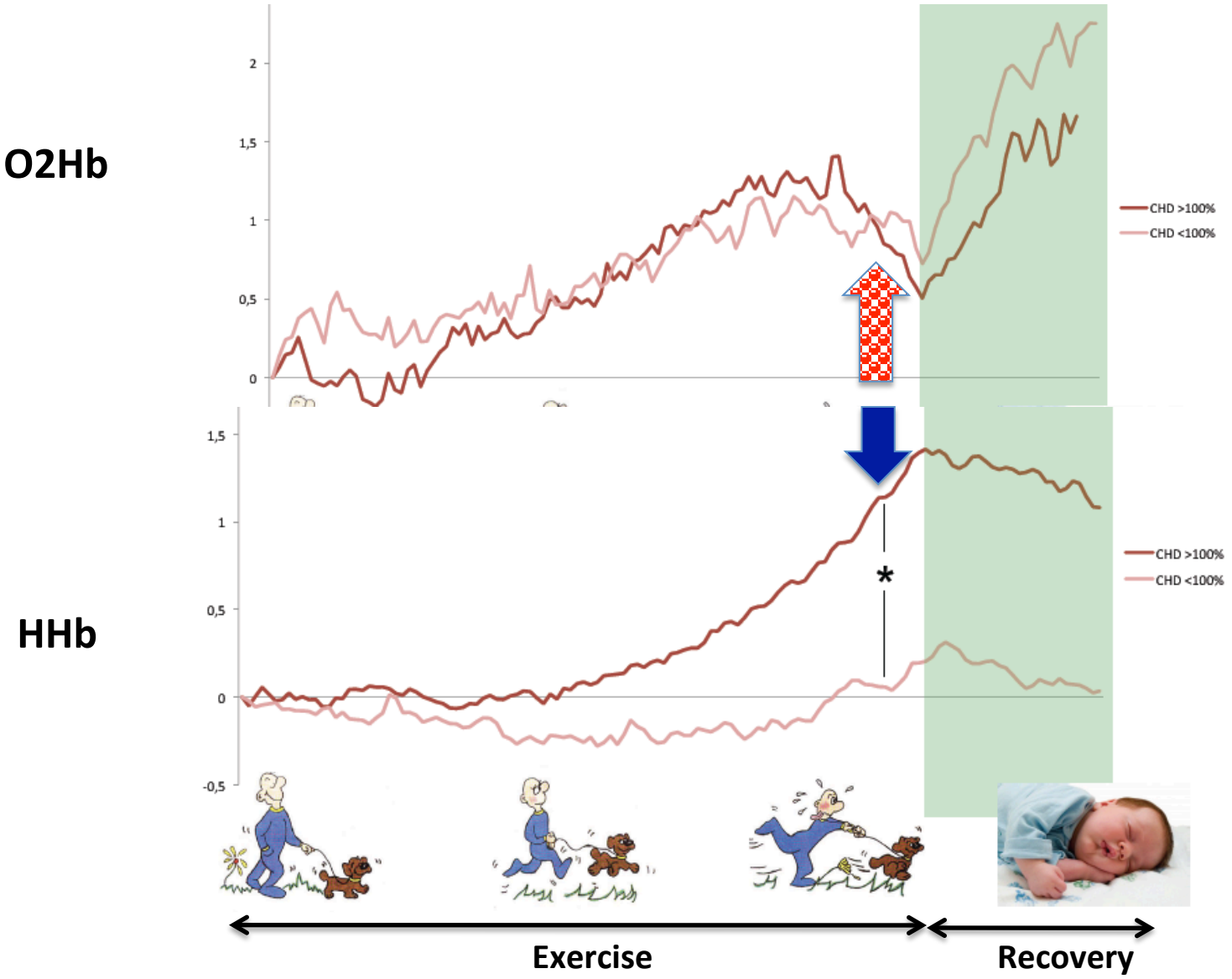
NO DIFFERENCE

>50e= 9 (72,4 years)

Cognitive performance, Fitness and Left PFC NIRS during exercise,



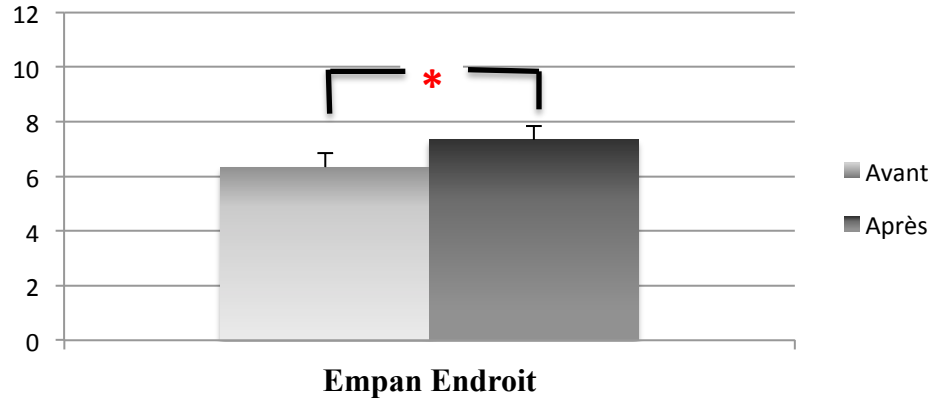
Cognitive performance, Fitness and Left PFC NIRS during exercise,

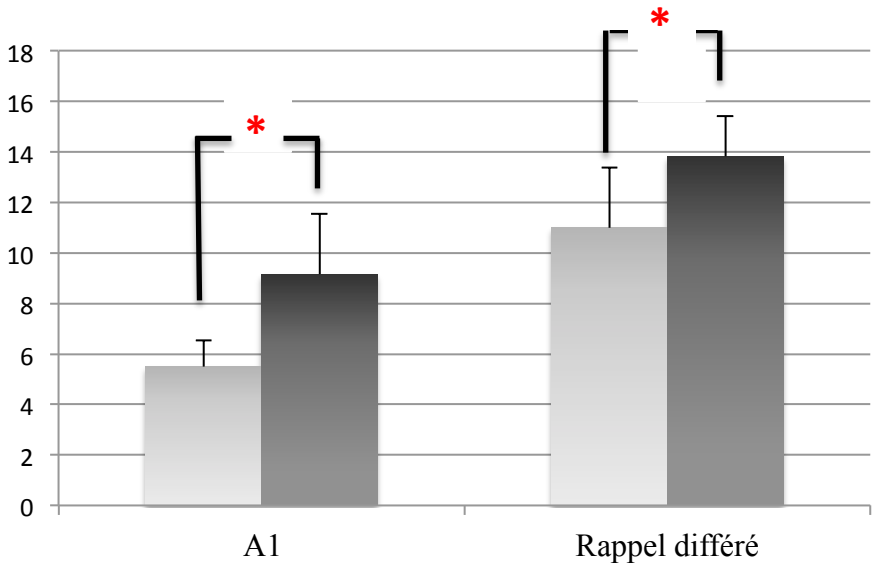


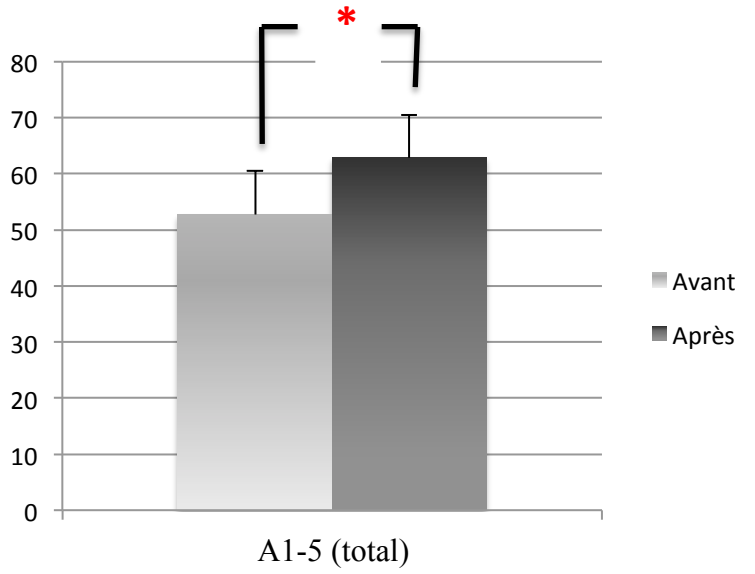
Effects of interval training on cognitive function and cerebral oxygenation in obese patients: a pilot study

J Drigny, V Gremeaux, O Dupuy, M Gayda, L Bherer, M Juneau, A Nigam

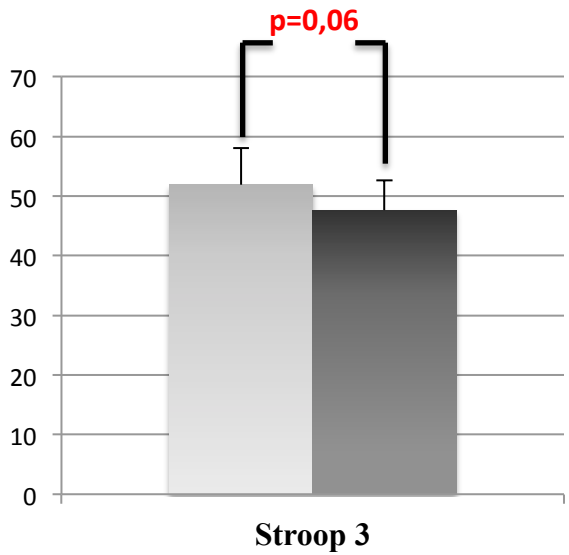
In revision, J Rehab Med

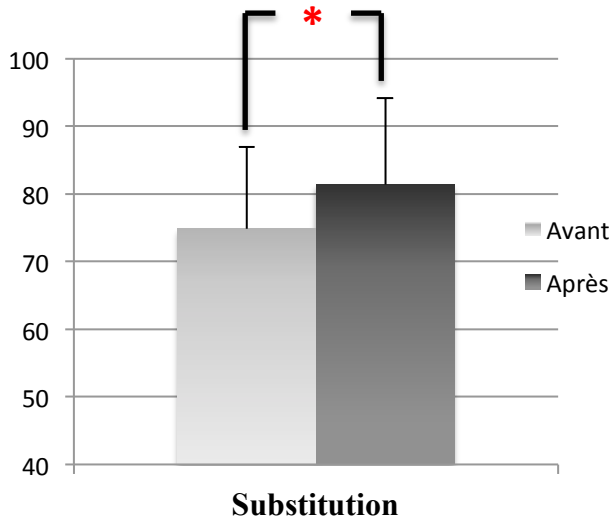






- Executive functions

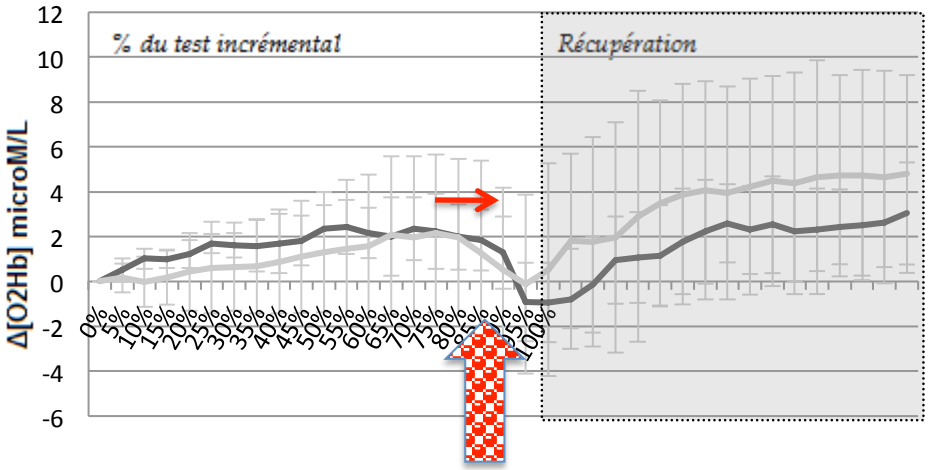




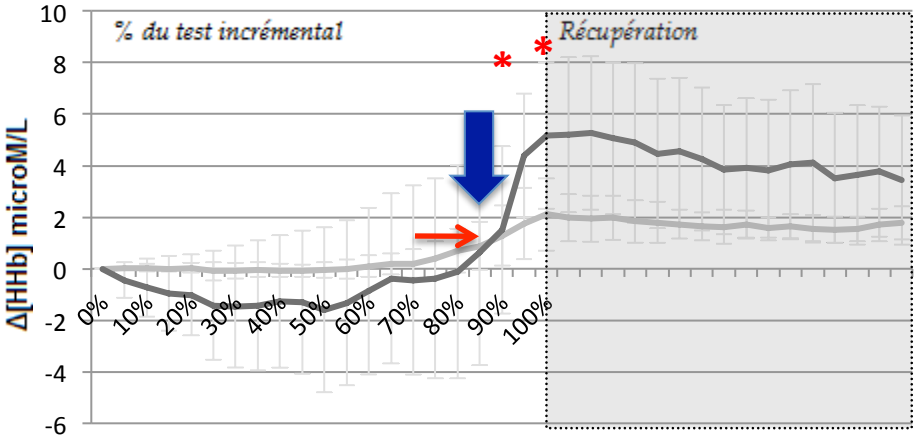
NIRS at the brain level during incremental exercise

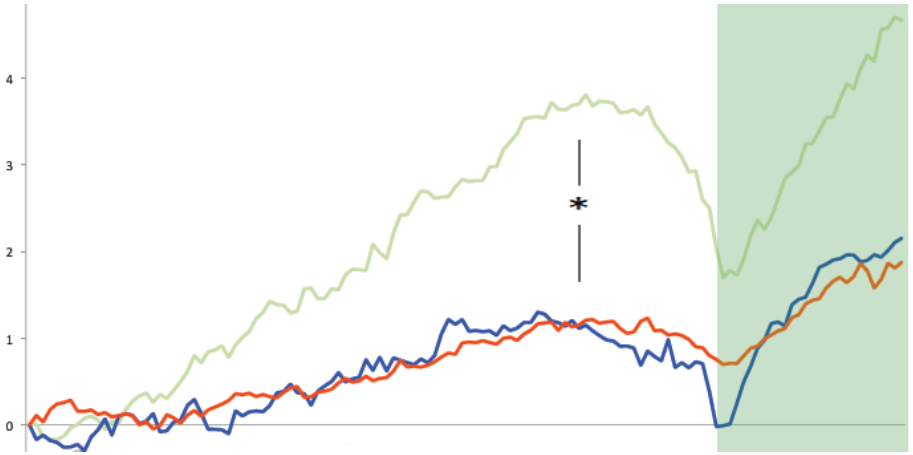
Before
After

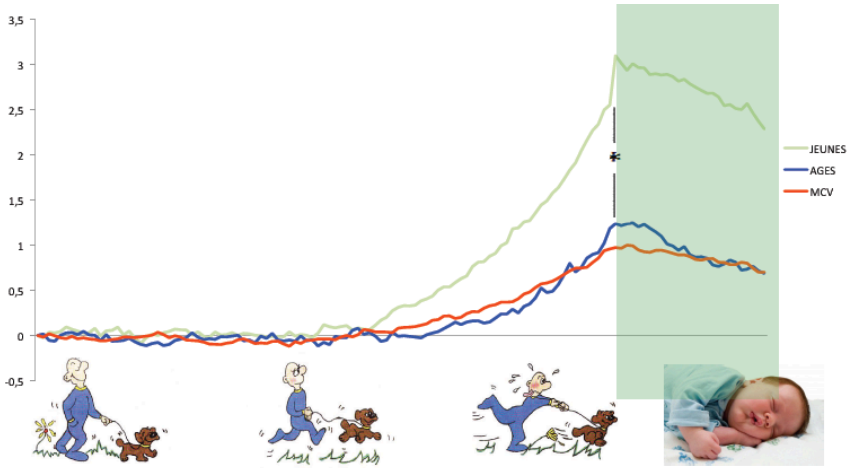
- O2Hb



- HHb







Aerobic interval training improves oxygen uptake efficiency by enhancing cerebral and muscular hemodynamics in patients with heart failure

Tieh-cheng Fu [a], Chao-Hung Wang [b], Pay-Shin Lin [c], Chih-Chin Hsu [a], Wen-Jin Cherng [b], Shu-Chun Huang [c], Min-Hui Liu [b], Cheng-Lin Chiang [d], Jong-Shyan Wang [d,*]

International Journal of Cardiology 167 (2013) 41–50

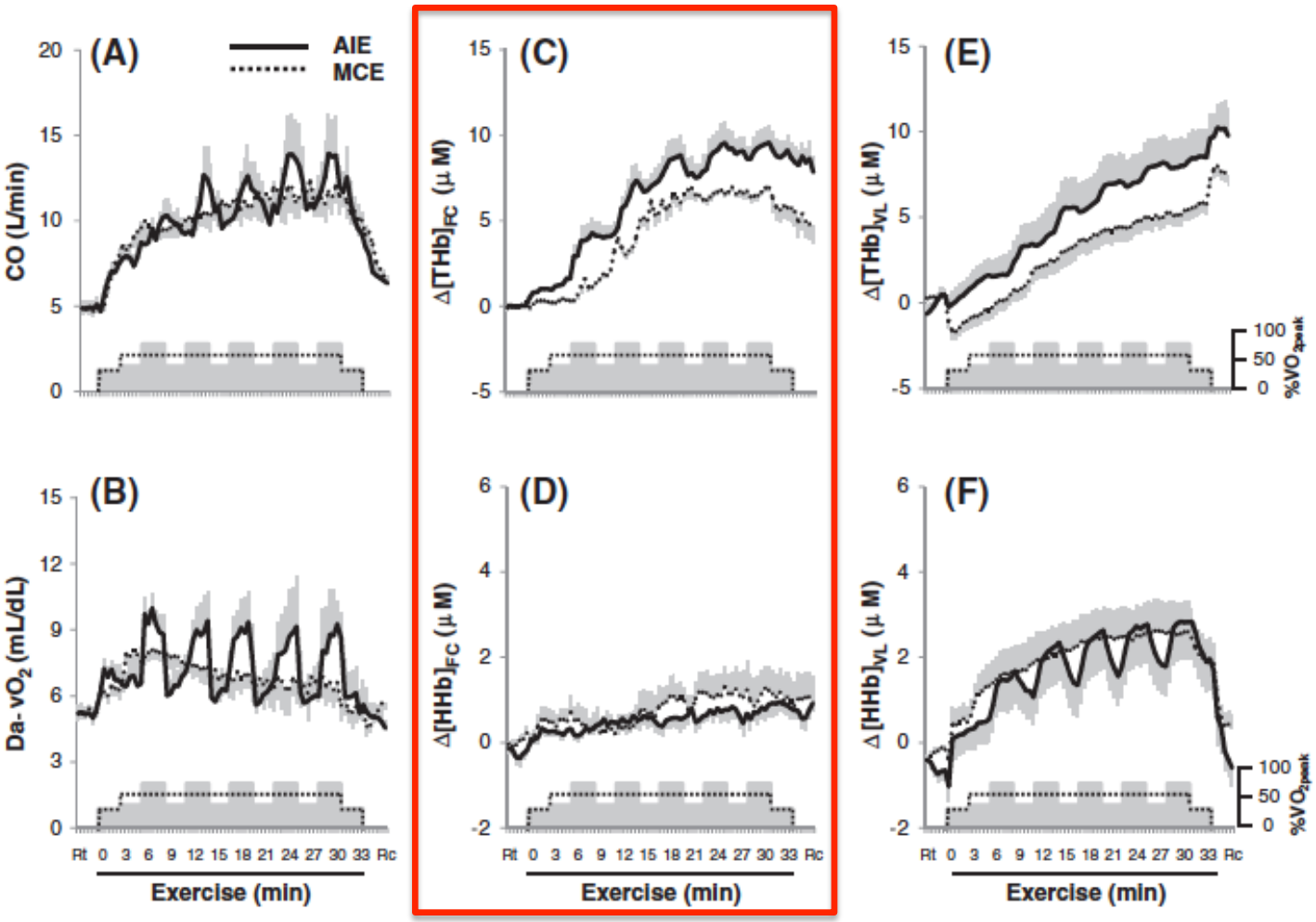


Fig. 2. Graphs show cardiac-cerebral-muscle hemodynamic responses to interval aerobic exercise (AIE) or moderate continuous exercise (MCE) in patients with heart failure (n = 6). CO, cardiac output (A); Da-vO_2, arteriovenous O_2 difference (B); $\Delta[THb]_{FC}$, perfusion in frontal cerebral lobe (C); $\Delta[HHb]_{FC}$, O_2 extraction in frontal cerebral lobe (D); $\Delta[THb]_{VL}$, perfusion in vastus lateralis muscle (E); $\Delta[HHb]_{VL}$, O_2 extraction in vastus lateralis muscle (F). Values are mean ± SEM.

AIT MICE Usual care

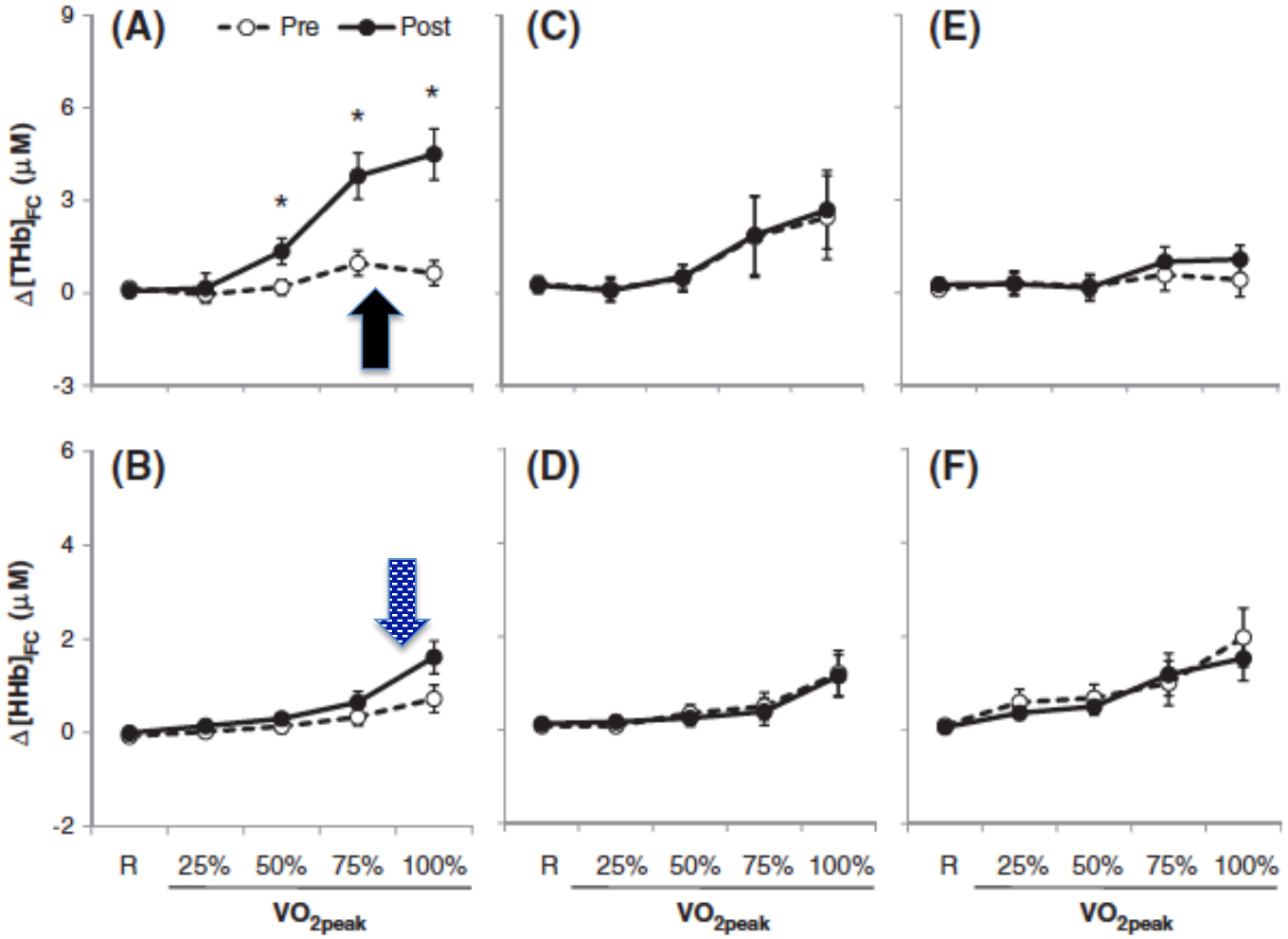


Fig. 6. The effects of aerobic interval training (A, B), moderate continuous training (C, D), and general healthcare (E, F) on perfusion ($\Delta[THb]_{FC}$) and O_2 extraction ($\Delta[HHb]_{FC}$) in frontal cerebral lobe during the graded exercise test in patients with heart failure. Pre, pre-intervention; Post, post-intervention. Values are mean ± SEM. *$P<0.05$, Pre *vs.* Post.

3- Understanding brain-muscle dialogue

- Central part of exercise intolerance
- Positive effects of exercise on cognitive functions
- Interaction physical – mental fatigue
- Identifying neuroplasticity induced by rehabilitation

Fatigue mentale et fatigue centrale

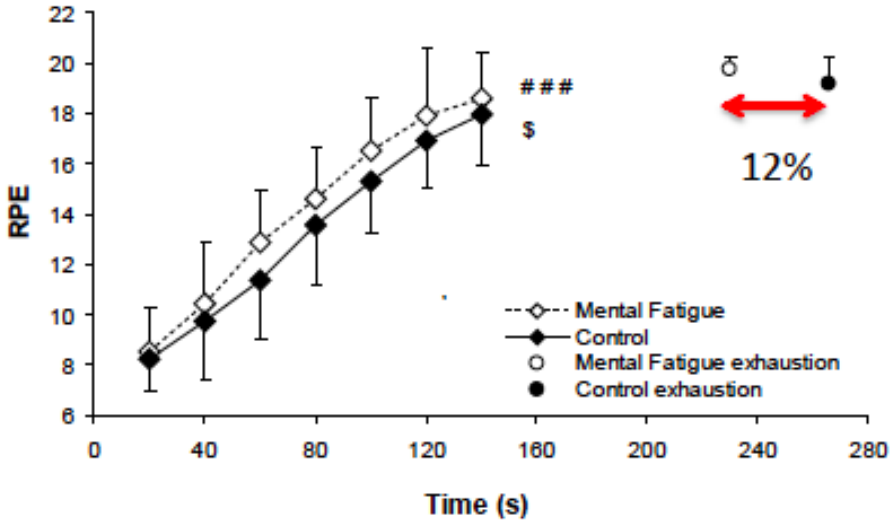
Pageaux, Marcora, Lepers (Med Sci Sport Exerc, 2013)

+

Tâche cognitive
1h30 AX-CP test
ou
Film (Contrôle)

Temps limite
20% CMV

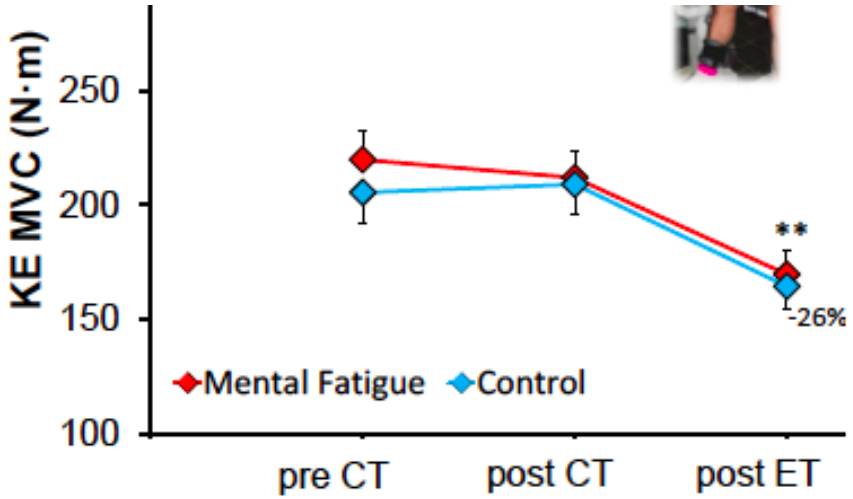
Perception de l'effort

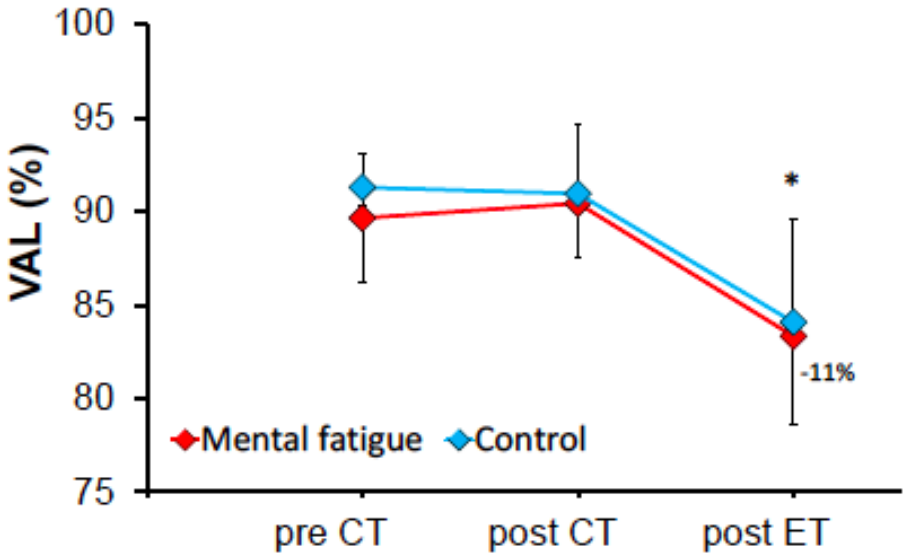


Ventrolateral part of frontal lobe

Suda et al, 2009

Activation maximale





3- Understanding brain-muscle dialogue

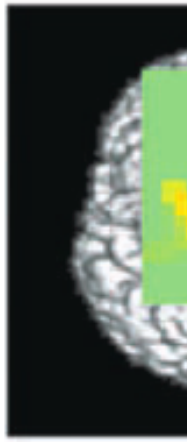
- Central part of exercise intolerance
- Positive effects of exercise on cognitive functions
- Interaction physical – mental fatigue
- Identifying neuroplasticity induced by rehabilitation

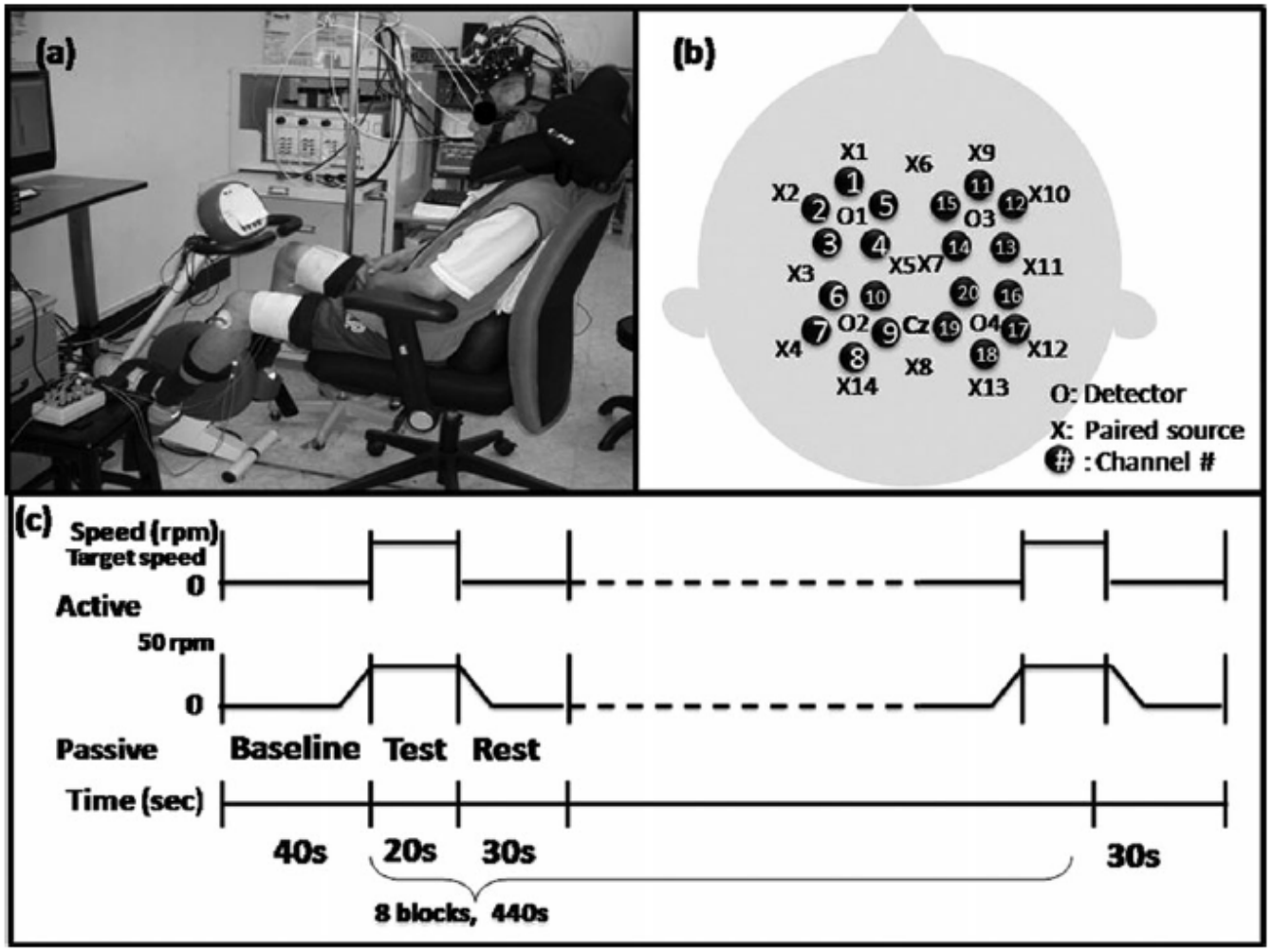
Hum Brain Mapp. **2013** Oct;34(10):2381-90. doi: 10.1002/hbm.22072. Epub 2012 Mar 28.

The cortical control of cycling exercise in stroke patients: an fNIRS study.

Lin PY[1], Chen JJ, Lin SI.

(a) Active





Representa
basal gangli
cycling with

figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

3- Understanding brain-muscle dialogue

- Central part of exercise intolerance
- Positive effects of exercise on cognitive functions
- Interaction physical – mental fatigue
- Identifying neuroplasticity induced by rehabilitation promoting mental imaging?

Adv Exp Med Biol. 2006;578:185-90.

NIRS-detected changes in
the motor cortex during mental rehearsal of physical activity (imaginary exercise).

Cooper CE, Pryor D, Hall C, Griffin M.

http://link.springer.com/chapter/10.1007%2F0-387-29540-2_30

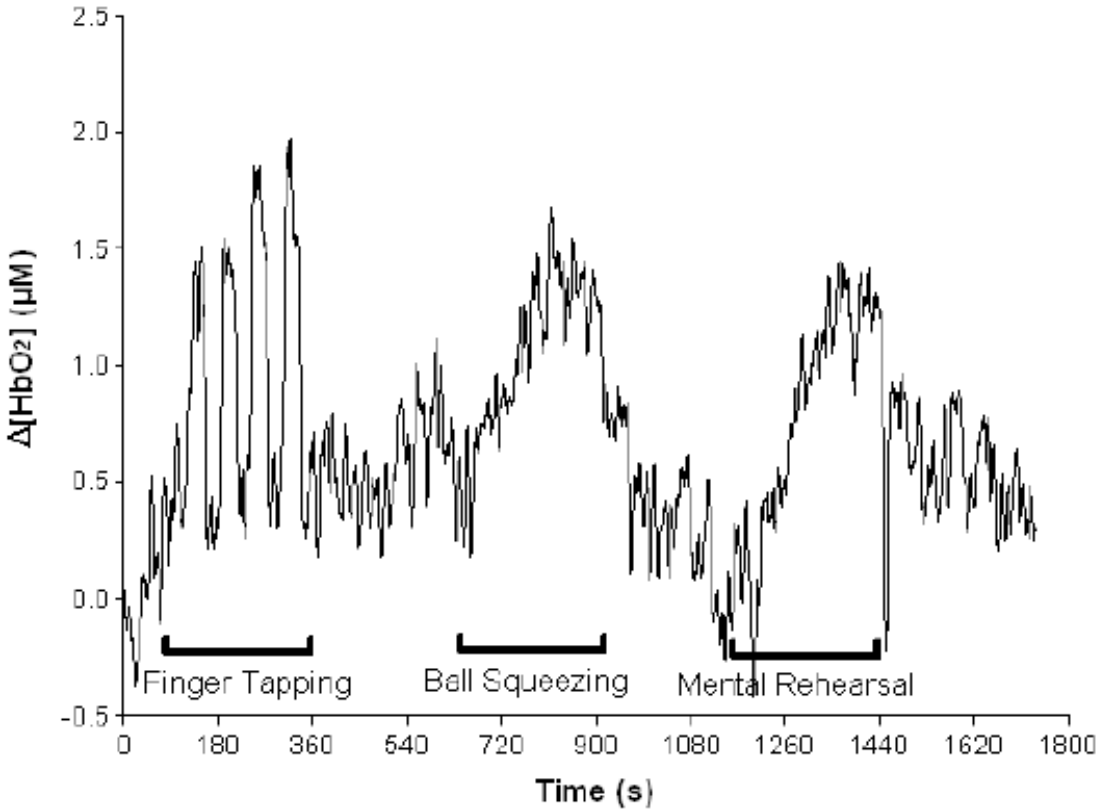


Figure 3. Magnitude of muscle hemoglobin oxygenation changes during the protocol. Data from Figure 2 averaged for all six subjects.

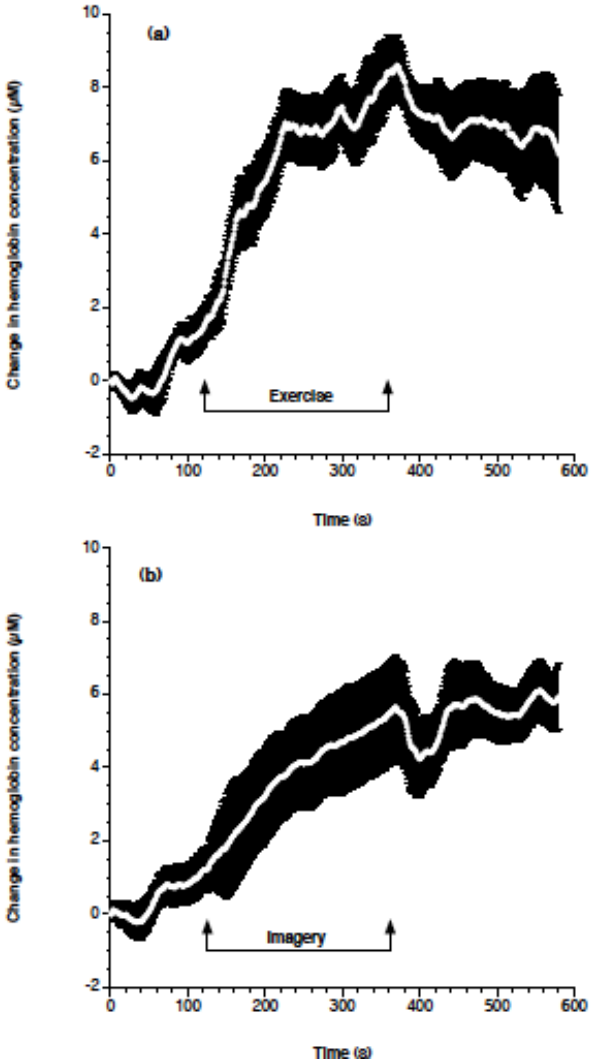
Adv Exp Med Biol. 2006;578:185-90.

NIRS-detected changes in
the arm during mental rehearsal of physical activity (imaginary exercise).

Cooper CE, Pryor D, Hall C, Griffin M.

http://link.springer.com/chapter/10.1007%2F0-387-29540-2_30

« Imagery of a motor task in an injured limb may be a way of promoting flow and healing in a limb that would otherwise be dormant »



Muscular and vascular applications

1- Assess microvascular function in healthy subjects and patients with cardio-metabolic diseases?

Journal of Biomedical Optics 17(7), 077010 (July 2012)

Reproducibility of near-infrared spectroscopy parameters measured during brachial artery occlusion and reactive hyperemia in healthy men

Sébastien Lacroix,[a,b,c] Mathieu Gayda,[a,b,c] Vincent Gremeaux,[a,b,d,e,f] Martin Juneau,[a,b,c] Jean-Claude Tardif,[b,c] and Anil Nigam[a,b,c]

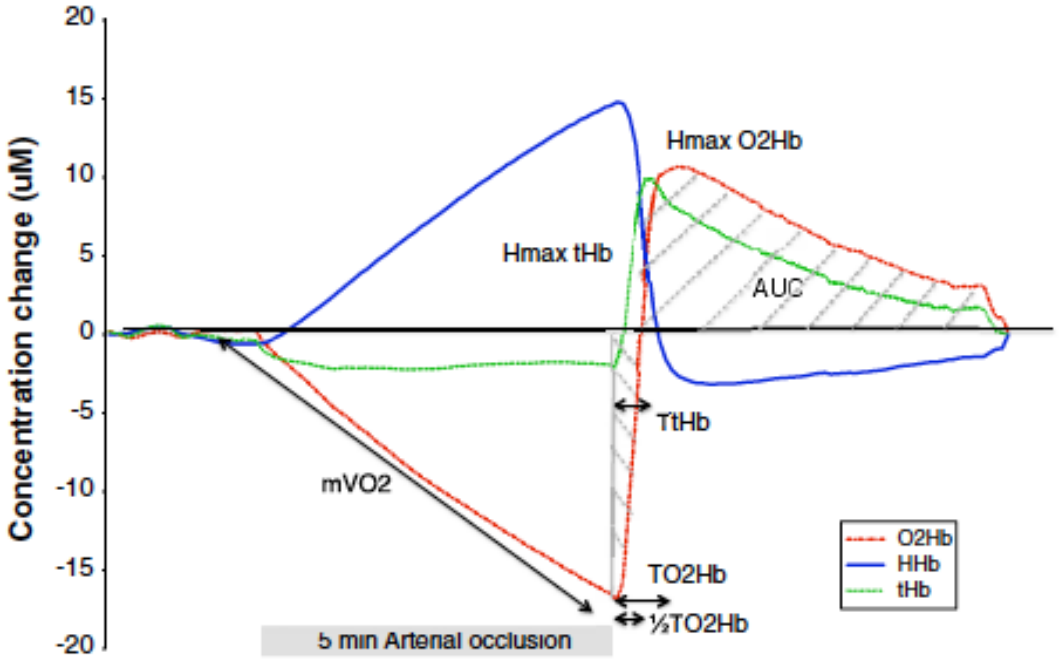


Fig. 1 Typical representation of NIRS signals during arterial occlusion and postocclusive reactive hyperemia.

(ICC from 0.85 to 1.00) for every parameter. NIRS parameters during reactive hyperemia are highly reproducible which enables their repeated measurement to study microvascular function in healthy subjects.

Muscle VO_2 and forearm blood flow repeatability during venous and arterial occlusions in healthy and coronary heart disease subjects

Clinical Hemorheology and Microcirculation xx (20xx) x–xx

Mathieu Gayda[a,b,c,*], Vincent Gremeaux[a,b,c,d], Joffrey Drigny[a,b], Martin Juneau[a,b,c] and Anil Nigam[a,b,c]

In conclusion, FBF and mVO_2 measured during VO were highly reproducible in healthy and CHD subjects, and a good agreement between mVO_2 measured by VO and AO was found. VO method using NIRS can be advantageous to assess microvascular function in clinical settings.
with a better patients comfort vs. the arterial occlusion

Cardiometabolic and traditional cardiovascular risk factors and their potential impact on macrovascular and microvascular function: Preliminary data

Mathieu Gayda[a,b,c,*], Martin Juneau[a,b,c], Jean-Claude Tardif[b,c], François Harel[b,c], Sylvie Levesque[d] and Anil Nigam[a,b,c]

Clinical Hemorheology and Microcirculation xx (20xx) x–xx

Only **A.U.C of O2Hb was related to CV risk numbers whereas FMD was not**

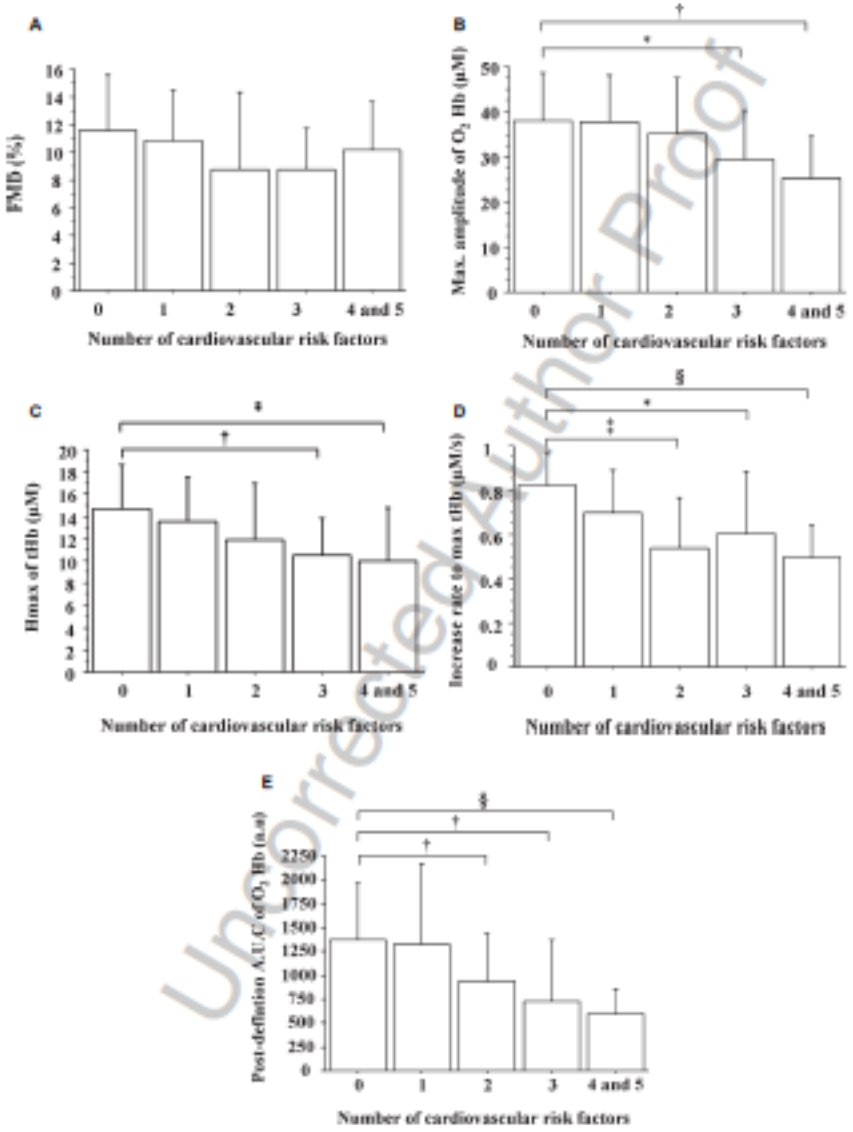


Fig. 1. (A,B,C,D,E): Relation between FMD, NIRS parameters and number of cardiovascular risk factors.

2- Assessing muscle metabolism during exercise?

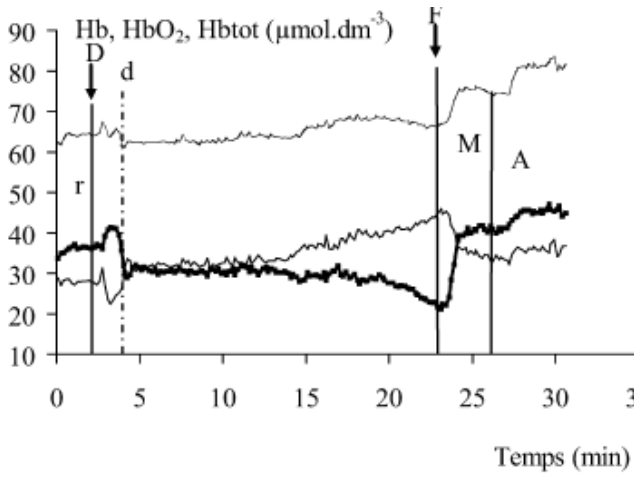
- Determining ventilatory treshold?
- Improvements after a training program
- During eccentric exercise → improving its prescription

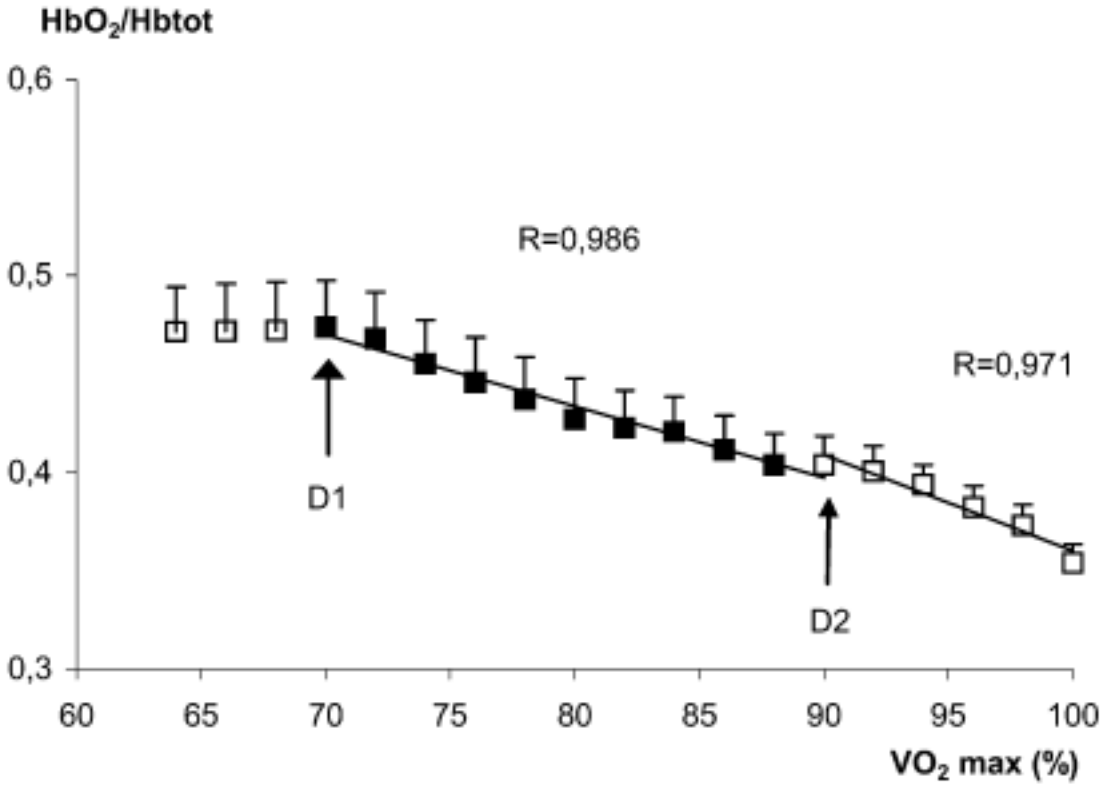
Evaluation of *vastus lateralis* oxygenation during incremental exercise using near infrared spectroscopy of haemoglobin

C. Dupouy[a], C. Dussault[a], J.-F. Kahn[b], E. Tinet[c], S. Avrillier[c], J.-P. Ollivier[d], J.-C. Jouanin[a,*]

SCIENCE & SPORTS

Science & Sports 22 (2007) 97–103





AT= 70% VOmax
D1=70% VO2max
R= 0.653, NS

RCP= 88% VO2max
D2= 89% VO2max
R= 0.747 , $p<0.05$

2- Assessing muscle metabolism during exercise?

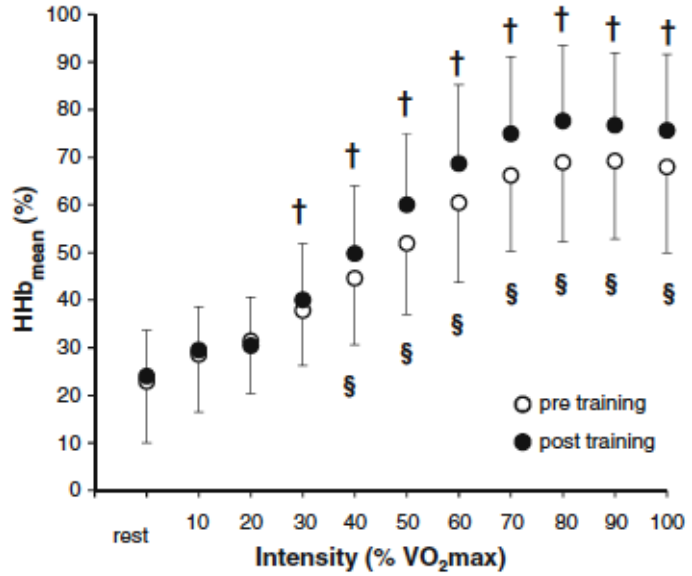
- Determining ventilatory treshold?
- Improvements after a training program
- During eccentric exercise → improving its prescription

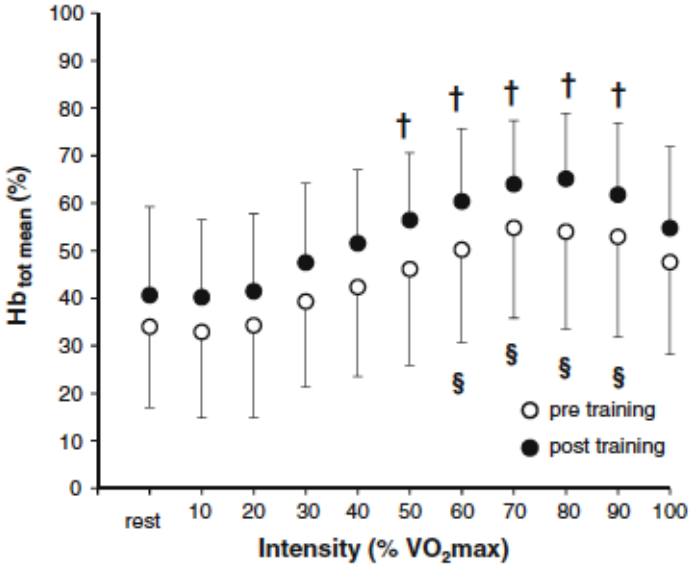
Effect of high-intensity interval training on the profile of muscle deoxygenation heterogeneity during incremental exercise

Eur J Appl Physiol

Fabrice Prieur · Patrick Mucci

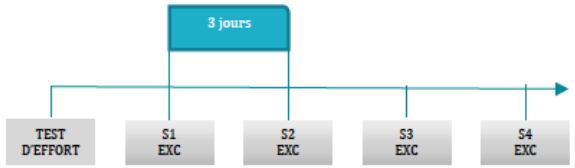
« HIT changes the muscle deoxygenation profile during incremental exercise, suggesting an improvement in the O2 extraction with training »





2- Assessing muscle metabolism during exercise?

- Determining ventilatory treshold?
- Improvements after a training program
- During eccentric exercise → improving its prescription



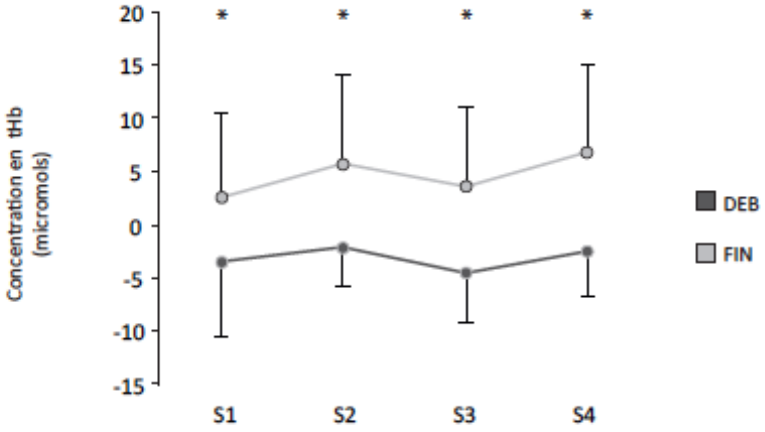


Fig 1. Différences des taux de tHb du vaste latéral entre le début et la fin d'exercice pour les différentes séances d'entrainement avec standard dérivation. n =11.

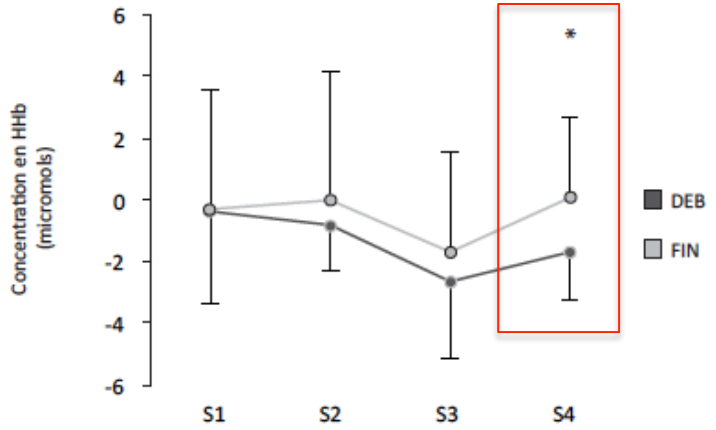


Fig 3. Différences des taux de HHb du vaste latéral entre le début et la fin d'exercice pour les différentes séances d'entrainement avec standard dérivation. n =11.

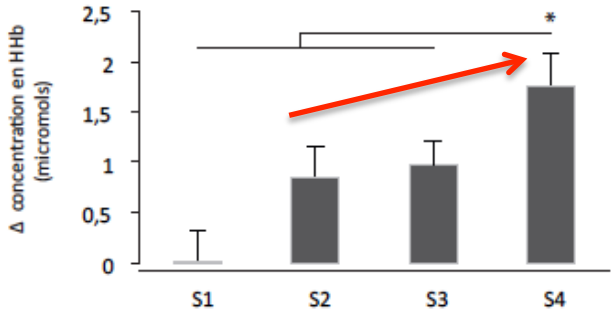
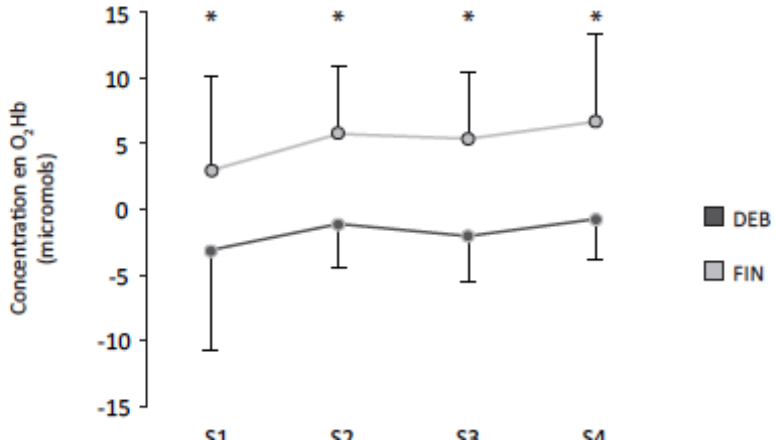


Fig 4. Évolution de la différence de concentration HHb du vaste latéral entre le début et la fin de l'exercice au cours des différentes séances d'entrainement avec standard dérivation. n =11.



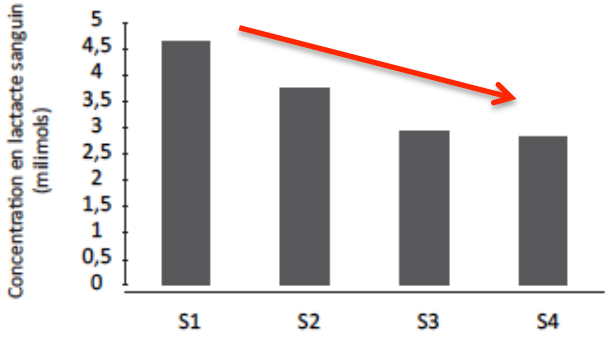
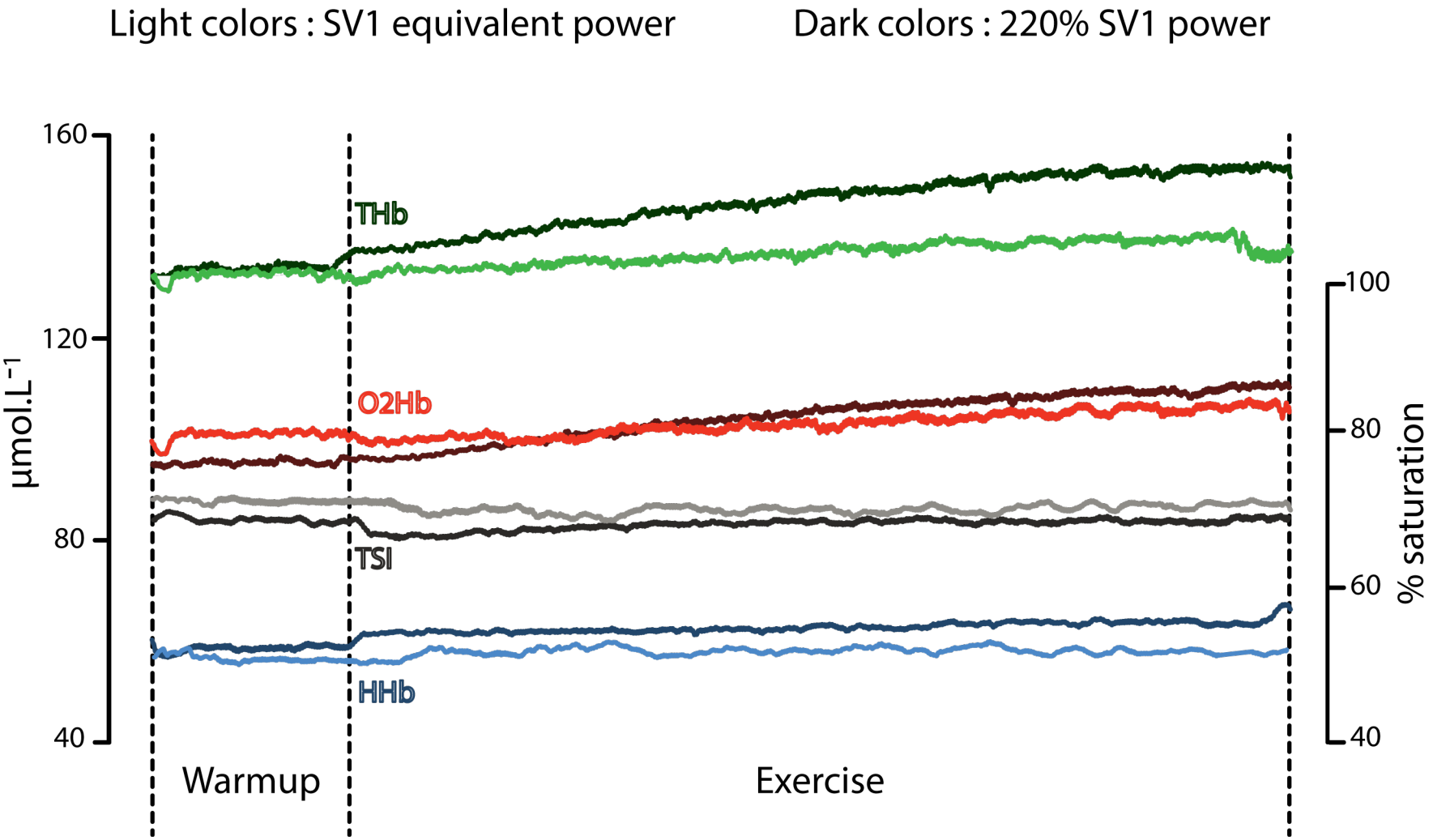


Fig 6. Évolution de la différence de concentration en lactate sanguin entre le début et la fin de l'exercice au cours des différentes séances d'entrainement. n =3.


Light colors : SV1 equivalent power
Dark colors : 220% SV1 power
160
120
80
40
µmol.L-1
THb
O2Hb
TSI
HHb
100
80
60
40
% saturation
Warmup
Exercise

Assessing stump prognosis in amputees?

Variables	D°	ICC	p
TcPO2	0	0,744	0,017
NIRS TSI	0	0,584902	0,0638819
TcPO2	30	0,65	0,057
NIRS TSI	30	0,704116	0,02562076

Thank you for your attention

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