

- 1 Des magnétophosphènes aux réseaux cérébraux
- 2 Système d'exposition au CM et traitement des données
- 3 Résultats: réseaux cérébraux et magnétophosphènes
- 4 Possibles applications en bioélectromagnétisme

1 – Des magnétophosphènes aux réseaux cérébraux

Les magnétophosphènes

Les **magnétophosphènes** sont une perception visuelle ("flashes"qui clignotent) pendant exposition à un champ magnétique (CM) intense.

Rapportés par Arsène D'Arsonval en 1896!

Magnétophosphènes : **au coeur des recommendations ICNIRP/IEEE guidelines**: effet le plus reproductible et au plus faible niveau de CM chez l'humain.



effects. In addition, the <u>only well established effects</u> in volunteers exposed to low frequency magnetic fields are the stimulation of central and peripheral nervous tissues and the <u>induction in the retina of phosphenes</u>, a perception of faint flickering light in the periphery of the visual field. The retina is part of the CNS and is regarded as an appropriate, albeit conservative, model for induced electric field effects on CNS neuronal circuitry in general.



An example of a synaptic polarization effect is attributed to the phenomenon of electro- and magnetophosphenes, which are visual effects resulting from electric currents or magnetic fields applied to the head (Adrian [B2]; Barlow [B5], [B6]; Baumgart [B7]; Bergeron et al. [B10]; Budinger et al. [B19]; Carstensen [B21]; Clausen [B24]; Lövsund et al. [B57], [B58]; Silny [B92]). Experimental evidence suggests that SÉANCE DU 2 MAI 1896

DISPOSITIFS POUR LA MESURE DES COURANTS ALTERNATIFS DE TOUTES FRÉQUENCES. Note de M. A. D'ARSONVAL.

Dans une communication verbale faite il y a environ un mois à la Société, j'avais annoncé qu'un champ magnétique alternatif intense (de 110 volts, 30 ampères et 42 périodes par seconde) donnait naissance, lorsqu'on y plongeait la tête, à des phosphènes et à un vertige pouvant aller chez quelques personnes jusqu'à la syncope. — Il est inutile d'avoir un champ aussi puissant pour constater la production des phosphènes. Avec des bobines ayant un faisceau de fils de fer doux de 5 centimètres de diamètre sur 30 centimètres de long, les phosphènes apparaissent. Ce champ magnétique alternatif modifie également la forme de la contraction musculaire et produit sur les êtres vivants d'autres effets qu'il est facile de mettre en relief, et dont je poursuis l'étude en ce moment.



Le cerveau: un réseau complexe



Connectivité fonctionnelle = DYNAMIQUE

EEG haute-résolution

Le cerveau: un réseau complexe

Research report

LTSI

Dynamic reorganization of functional brain networks during picture naming

Mahmoud Hassan ^{*a,b,**}, Pascal Benquet ^{*a,b*}, Arnaud Biraben ^{*a,b,c*}, Claude Berrou ^{*d,e*}, Olivier Dufor ^{*d,e*} and Fabrice Wendling ^{*a,b*}



➔ Résolution temporelle bien meilleure que l'IRM fonctionnelle (ms versus s)



➔ Méthode plus sensible que les analyses EEG classiques basées sur la puissance EEG dans des bandes de fréquence (alpha, beta...) Functional connectivity disruptions correlate with cognitive phenotypes in Parkinson's disease



M. Hassan^{a,b,*}, L. Chaton^e, P. Benquet^{a,b}, A. Delval^{c,d,e}, C. Leroy^{c,d,e}, L. Plomhause^{c,d,e}, A.J.H. Moonen^g, A.A. Duits^g, A.F.G. Leentjens^g, V. van Kranen-Mastenbroek^g, L. Defebvre^{c,d,f}, P. Derambure^{c,d,e}, F. Wendling^{a,b}, K. Dujardin^{c,d,f}

Peut-on identifier les réseaux cérébraux impliqués dans la perception des magnetophosphenes?

→Plus généralement: peut-on identifier les réseaux cérébraux modulés par l'exposition aux EMF?

2 – Système d'exposition au CM et traitement des données

Protocole experimental – EEG-HR / exposition au CM (N=3)





IRM cérébral (3T Biograph, Siemens)



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EEG-HR (128 canaux, Neuroscan, USA)



### La méthode de connectivité de sources - principe



### Caractérisation des réseaux fonctionnels

Nous avons étudié **deux paramètres centraux** pour l'organisation des réseaux cérébraux:



Augmentation du coefficient de clustering

→ Coefficient de participation : Traitement global/distant d'information



Diminution du coefficient de participation

# 3 – Résultats: réseaux cérébraux et magnétophospènes

# Réseau cérébral fonctionnel – CM à 60 Hz, 50 mT



## Reconstruction des réseaux fonctionnels – sham vs 50 mT



## Reconstruction des réseaux fonctionnels – sham vs 50 mT



Activation de la voie ventrale



→ La méthode de connectivité de sources identifie un réseau impliqué dans la perception visuelle, plus précisément dans l'identification de « l'objet » qui est perçu.

#### frontiers in INTEGRATIVE NEUROSCIENCE



The neural bases of spatial frequency processing during scene perception

Louise Kauffmann^{1,2}, Stephen Ramanoël^{1,2} and Carole Peyrin^{1,2}*

¹ University Grenoble Alpes, LPNC, Grenoble, France

² CNRS, LPNC, Université Pierre Mendès France, Grenoble, France



# 4 – Possibles applications en bioélectromagnétisme

### Possibles applications / perspectives

- →La méthode de connectivité de source apparaît prometteuse pour identifier les réseaux cérébraux modulés par l'exposition à des CEM.
- → Preuve de principe concluante, validation en cours sur un échantillon plus large (N=20) avec 11 conditions expérimentales (CM 50 Hz, 0 à 50 mT).



- ➔ Intérêt pour les études de stimulation cérébrale thérapeutique: clarifier les cibles / mécanismes qui sous-tendent les effets comportementaux observés.
- →Applicable également pour les études RF associées avec des effets sur la puissance alpha dans l'EEG, l'EEG de sommeil ou des tests cognitifs: quels réseaux sont impactés?





# Merci pour votre attention! julien.modolo@inserm.fr

(L'équipe recrute un post-doc de 2 ans avec un background biophysique / dosimétrie pour un projet ANR, me contacter en cas d'intérêt!)

### La méthode de connectivité de sources - concepts

peut-on reconstruire les sources d'activité Comment neuronale à partir de signaux de scalp?

#### Problème inverse

# EEG(t) = G.S(t)

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### Problème direct

### Limites des approches classiques en neuroimagerie

→ Au niveau des signaux EEG (scalp), les signaux enregistés sont un "mélange" d'activité de sources corticales, ce qui biaise les estimations de coherence ("mixing problem"¹).

→ La puissance spectrale n'est pas suffisante: comment interpreter une augmentation/diminution de puissance alpha par exemple?

→ L'aspect "réseaux" est le plus souvent ignoré, et est pourtant plus sensible que l'analyse spectrale seule.

Bioelectromagnetics 38:425-435 (2017)

Human Exposure to Power Frequency Magnetic Fields Up to 7.6 mT: An Integrated EEG/fMRI Study

BERG

Julien Modolo,  1,2,3,4,5  Alex W. Thomas,  1,2,3  and Alexandre Legros  1,2,3,6,7* 

→ L'IRM fonctionnelle est un outil adapté, mais le CM maximum ne suffit pas à induire de magnetophosphenes.

1: Hassan and Wendling, IEEE Signal Processing Magazine, 2018.

**BIO ELECTRO MAGNETICS** 







Laboratoire Traitement du Signal et de l'Image - UMR Inserm U 1099

### Réseau cérébral fonctionnel – CM à 50 Hz, 0 mT



### **Reconstructed networks**

#### N=20 results – alpha band – 0 and 50 mT



### **Reconstructed networks**

#### N=20 results – alpha band – 0 and 50 mT



5 highest participation

#### **ALPHA – clustering:**

sig with perception curve	e
'superiorfrontal R'	3.69E-04
sig with MF	
'superiorfrontal R'	5.87E-04

#### **ALPHA** – participation:

sig with perception curve	
'parsorbitalis L'	0.0002
'lingual L'	0.0003
'parsopercularis L'	0.0004
'temporalpole L'	0.0007
'inferiorparietal L'	0.0013
'frontalpole L'	0.0032
'precuneus L'	0.0043
'supramarginal R'	0.0047
sig with MF	
'lingual L'	0.0002
'parsorbitalis L'	0.0002
'temporalpole L'	0.0002
'inferiorparietal L'	0.0006
'parsopercularis L'	0.001
'precuneus L'	0.0011
'frontalpole L'	0.0017
'supramarginal R'	0.0021
'rostralanteriorcingulate l	0.0044
'pericalcarine L'	0.007

#### **BETA– clustering:**

sig with perce	eption curve	
	'lingual R'	0.000225034
	'isthmuscingulate R'	0.000733624
sig with MF		
	'lingual R'	0.0003
	'isthmuscingulate R'	0.0006
	'precuneus R'	0.0013
	'isthmuscingulate L'	0.0026
	'lateraloccipital R'	0.0029

#### **BETA**– participation:

sig with perception curve	
'precuneus L'	1.06E-04
sig with MF	
'precuneus L'	5.08E-05







Supramarginal R – border of TPJ

#### ALPHA – participation: mostly LEFT effects

0.0002

0.0003

0.0007

0.0032

0.0043

0.0047

0.0002

0.0002

0.0002

0.0006

0.001

0.0011

0.0021

0.0044

0.007

sig with perception curve 'parsorbitalis L'

'parsopercularis L' 'temporalpole L'

'inferiorparietal L' 'frontalpole L'

'supramarginal R'

'parsorbitalis L'

'temporalpole L'

'inferiorparietal L'

'parsopercularis L'

'rostralanteriorcingulate I

'precuneus L'

'frontalpole L' 'supramarginal R'

'pericalcarine L'

'precuneus L'

sig with MF

'lingual L'

'lingual L'

TPJ	
12	340

#### nature neuroscience



Electrocorticography links human temporoparietal junction to visual perception

#### Left hemisphere significant brain regions for participation coefficient (alpha):



Precuneus L + anterior cingulate (DMN)

Percicalcarine+lingual=visual cortex

Localized frontal activation

Temporo-basal pathway



#### BETA- clustering: mostly RIGHT effects

sig with perce	ption curve	
	'lingual R'	0.000225034
	'isthmuscingulate R'	0.000733624
sig with MF		
	'lingual R'	0.0003
	'isthmuscingulate R'	0.0006
	'precuneus R'	0.0013
	'isthmuscingulate L'	0.0026
	'lateraloccipital R'	0.0029



Precuneus R + both isthmus cingulate (DMN)



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Alpha/participation significant regions



Beta/clustering significant regions



### Minor results

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# ALPHA – participation JT

#### Results with JT test (linear trend) + correlation with perception curve Alpha JT FDR Alph







#### Alpha JT FDR Alpha JT (B/B-H)

'lingual L'
'temporalpole L'
'parsorbitalis L'
'supramarginal R'
'inferiorparietal L'
'parsopercularis L'
'precuneus L'
'rostralanteriorcingulate R'
'frontalpole L'
'parstriangularis L'
'entorhinal R'
'fusiform L'
'paracentral R'

'parahippocampal L'

'lingual L' 'parsorbitalis L' 'supramarginal R' 'temporalpole L'

# Middle Frontal R (FDR)Precuneus L (FDR/B/B-H)Perception curve correlation



FDR:<br/>resists to False Detection Rate<br/>B:<br/>resists to Bonferonni-correction<br/>B-H:<br/>resists to Bonferonni-Holm correction<br/>P:<br/>resists to correlation with perception curve (with B/B-H)







#### Alpha P FDR

#### Alpha P (B/B-H)

'parsorbitalis L' 'lingual L' 'parsopercularis L' 'temporalpole L' 'inferiorparietal L' 'frontalpole L' 'precuneus L'

'supramarginal R'

'lingual L' 'parsopercularis L' 'parsorbitalis L' 'temporalpole L'

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#### **ALPHA** – participation

### Comparison of FDR-corrected maps - linear trend+P







#### Alpha JT FDR



#### Alpha P FDR

'parsorbitalis L' 'lingual L' 'parsopercularis L' 'temporalpole L' 'inferiorparietal L' 'frontalpole L' 'precuneus L' 'supramarginal R'

#### ALPHA – participation FDR common map (both linear trend and perception)









#### **Alpha JT FDR**

'lingual L' 'temporalpole L' 'parsorbitalis L' 'supramarginal R' 'inferiorparietal L' 'parsopercularis L' 'precuneus L' 'rostralanteriorcingulate R' frontatpole i pericalcarine L' parstriangularis L entorhinal R' 'frontalpole R' 'fusiform L' paracentral R' parahippocampal L

#### **FDR contrast map** (linear trend – perception curve)







#### Alpha P FDR

'parsorbitalis L' 'lingual L' 'parsopercularis L' 'temporalpole L' 'inferiorparietal L' 'frontalpole L' 'precuneus L' 'supramarginal R'

#### **Beta - clustering**

#### Results with **JT test (linear trend)** + **correlation with perception curve**



#### Theta – no results

Alpha – superior frontal R (FDR/B/B-H/P)

<u>FDR:</u> resists to False Detection Rate <u>B:</u> resists to Bonferonni-correction

<u>B-H:</u> resists to Bonferonni-Holm correction

P: resists to correlation with perception curve (with B/B-H)

Beta JT FDR 'isthmuscingulate R' 'lingual R' 'precuneus R' 'isthmuscingulate L'

'caudalmiddlefrontal R'

Beta J+P 'isthmuscingulate R' (B/B-H) 'lingual R'